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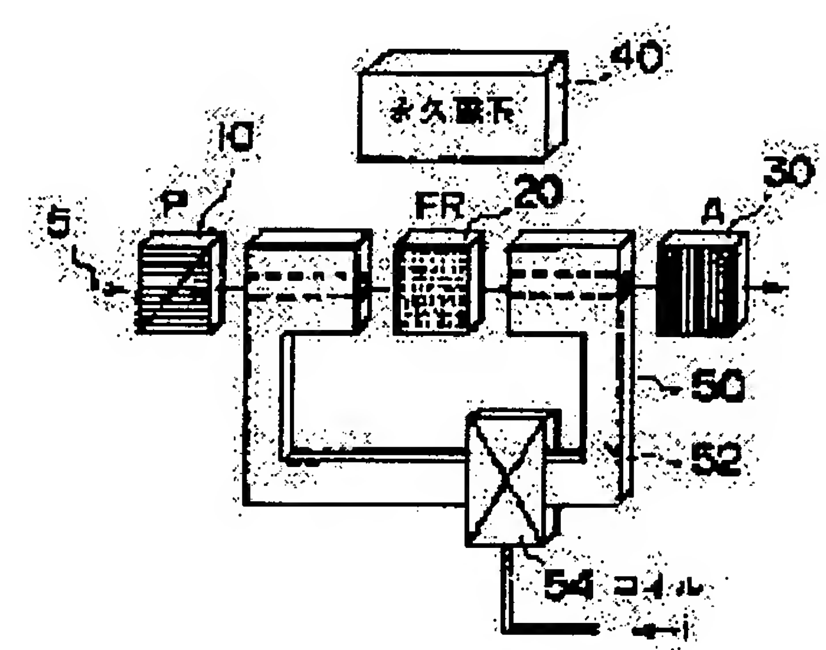
(54) OPTICAL VARIABLE ATTENUATOR

(57)Abstract:
PROBLEM TO BE SOLVED: To reduce temp. dependency and wavelength dependency of an attenuation amount and a drive current and to enable easily applying it to an optical transmitter by setting a polarization direction of an analyzer in the state substantially orthogonally intersecting with the polarization direction of a light beam in the case that the rotation of the polarization direction in a magneto-optical crystal doesn't exist.
SOLUTION: When the light beam 5 is supplied to a polarizer 10, the light of liner polarization having the same polarization direction as the polarization direction of the polarizer 10 is outputted. The light of the linear polarization passes through a Faraday element 20, and then, the polarization direction of the passing light is rotated by a Faraday effect according to a size of a magnetization vector occurring in the direction of the light beam 5. Then, in such a case, the polarizer 10 and the analyzer 30 are constituted so that the polarization direction of the light beam 5 in the state (magnetic field in the optical axial direction is zero) that Faraday rotation in the Faraday element 20 doesn't exist becomes the state nearly orthogonally intersecting with the polarization direction of the analyzer 30.



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CLAIMS

[Claim(s)]
[Claim 1] It is the optical variable attenuator which is equipped with the following and characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state substantially with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction.
[Claim 2] It is the optical variable attenuator according to claim 1 which has further the polarizer which generates the aforementioned light beam, and is characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state as substantially as the polarization direction of the aforementioned polarizer.
[Claim 3] The polarization direction of the aforementioned analyzer and the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal are an optical variable attenuator according to claim 1 or 2 characterized by being set up at the angle of **30 degrees 80 degrees.
[Claim 4] It is the optical variable attenuator which is equipped with the following, and a magnetic field is impressed to the aforementioned magneto optics crystal, and is characterized by penetrating a part of aforementioned light beam [at least] even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal. The permanent magnet which generates the magnetic field which it is prepared in either the interior of the aforementioned magnetic circuit, or near, and is electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal in parallel.
[Claim 5] It is the optical variable attenuator which is equipped with the following, and a magnetic field is impressed to the aforementioned magneto optics crystal, and is characterized by penetrating a part of aforementioned light beam [at least] even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal. The permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal at an angle smaller than 90 degrees.
[Claim 6] It is the optical variable attenuator according to claim 4 or 5 which has further the analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction, and is characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state substantially with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal.
[Claim 7] The optical variable attenuator which is characterized by providing the following and which decreases the power of a light beam. The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam. The yoke with which the magnetic field for being impressed by the aforementioned magneto optics crystal was generated, and the aforementioned magneto optics crystal was inserted in the internal gap.
[Claim 8] The aforementioned magnetic circuit is an optical variable attenuator according to claim 7 characterized by

having further at least one coil for being prepared near the gap of the aforementioned yoke and making the aforementioned gap generate a magnetic field electrically.
[Claim 9] The optical variable attenuator according to claim 7 which it has further the 1st lens for converging the aforementioned light beam and carrying out incidence to the aforementioned magneto optics crystal, and the interval of the gap of the aforementioned yoke is narrowed according to the size of the light beam which it converged with the 1st lens of the above, and is characterized by impressing efficiently the magnetic field generated about this gap to the aforementioned magneto optics crystal.
[Claim 10] The optical variable attenuator according to claim 9 characterized by including the 2nd lens for setting the light beam by which convergence was carried out [aforementioned] as a predetermined size after the light beam by which convergence was carried out [aforementioned] passes the aforementioned magneto optics crystal.
[Claim 11] The light amplifier which has the gain property which is the light amplifier which amplifies the lightwave signal which has a predetermined wavelength-range region, and has a wavelength dependency. It is [the aforementioned wavelength dependency of gain / in / the aforementioned light amplifier / this lightwave signal is decreased in adjustable using rotation of the polarization direction of the lightwave signal in a magneto optics crystal and / in a damping property], and / a reverse wavelength dependency substantially. It is the light amplifier equipped with the above, and while the aforementioned lightwave signal declines, it is characterized by reducing the aforementioned wavelength dependency of the gain in the aforementioned light amplifier.
[Claim 12] It is the light amplifier according to claim 11 which is equipped with the following and characterized by setting up the polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal in the predetermined magnitude of attenuation so that the wavelength dependency of the aforementioned reverse may be acquired substantially. The aforementioned optical variable attenuator is a magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned lightwave signal. The analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction.
[Claim 13] It is the optical variable attenuator which is equipped with the following and characterized by setting up the polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal in the predetermined magnitude of attenuation so that a reverse wavelength dependency may be substantially acquired with the wavelength dependency of the gain of the aforementioned light amplifier. The magneto optics crystal which it is [magneto optics crystal] an optical variable attenuator for connecting with a light amplifier, and reducing the wavelength dependency of the gain in the aforementioned light amplifier, and decreasing a lightwave signal, and makes adjustable rotate the polarization direction of the aforementioned lightwave signal. The analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction.
[Claim 14] The optical variable attenuator characterized by controlling the polarization direction of the aforementioned light beam in the aforementioned magneto optics crystal so that it may have the following and the output power of the aforementioned optical variable attenuator which carried out the monitor by the aforementioned output side electric eye may become a predetermined value. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator. The output side electric eye which branches a part of output light of the aforementioned optical variable attenuator, and carries out the monitor of the output power.
[Claim 15] The optical variable attenuator characterized by controlling the polarization direction of the aforementioned light beam in the aforementioned magneto optics crystal so that it may have the following and a ratio with the output power of the aforementioned optical variable attenuator which carried out the monitor by the input control power and the aforementioned output side electric eye of the aforementioned light beam which carried out the monitor by the aforementioned input-side electric eye may become a predetermined value. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator. The input-side electric eye which carries out the monitor of the input control power of the light beam inputted into the aforementioned magneto optics crystal. The output side electric eye which carries out the monitor of the output power of the aforementioned optical variable attenuator.
[Claim 16] the aforementioned analyzer -- a birefringence crystal -- containing -- the aforementioned analyzer **** -- the optical variable attenuator according to claim 14 or 15 characterized by having further the aperture which leads a

part of light beam by which the separation chip box was carried out in polarization to the aforementioned output side electric eye

[Claim 17] It is the optical variable attenuator which is equipped with the following and characterized by mounting the aforementioned magnetic circuit in a case so that the direction of the aforementioned gap may be the height direction of the aforementioned case substantially. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam. The magnetic circuit which generates the magnetic field for being impressed by the aforementioned magneto optics crystal about an internal gap. The case for holding the aforementioned magneto optics crystal and the aforementioned magnetic circuit, and mounting in a substrate.

[Claim 18] The optical variable attenuator which is characterized by providing the following and which decreases the power of a light beam. The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam. The aforementioned magnetic circuit which is close so that the aforementioned point may sandwich the aforementioned magneto optics crystal including the yoke of a horseshoe shape configuration with which it is the magnetic circuit which generates the magnetic field for being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and the front point is thinner than other portions.

[Claim 19] It is the optical variable attenuator according to claim 18 which the aforementioned magnetic circuit consists of permanent magnets, and has further the electromagnet which generates electrically the magnetic field for being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and is characterized by the point of the yoke of the aforementioned permanent magnet being close from the aforementioned electromagnet with the aforementioned magneto optics crystal.

[Claim 20] It is the optical variable attenuator characterized by maintaining the aforementioned magnetic field even if it is the optical variable attenuator which decreases the power of a light beam, it has the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam, and the magnetic circuit which generates electrically the magnetic field for having the yoke which contains the half-hard magnetic substance in part at least, and being impressed by the aforementioned magneto optics crystal by drive current and supply of the aforementioned drive current stops.

[Claim 21] The aforementioned yoke is an optical variable attenuator according to claim 20 characterized by the ability to change gradually the size of the magnetic field generated in the aforementioned magnetic circuit by having partially two or more half-hard magnetic substance with which the magnetization in a saturation state differs, and controlling magnetization for every aforementioned half hard magnetic substance.

[Claim 22] The optical variable attenuator which is equipped with the following and characterized by impressing the magnetic field of the aforementioned magnetic circuit to the flat surface which consists of aforementioned light beams from which polarization was separated as the wedge-like birefringence crystal of the above 1st perpendicularly substantially at the aforementioned magneto optics crystal. The 1st wedge-like birefringence crystal which is the optical variable attenuator which decreases the power of a light beam, and performs polarization separation of the aforementioned light beam. The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam where polarization was separated as the wedge-like birefringence crystal of the above 1st. The magnetic circuit which generates the magnetic field for being substantially impressed by the aforementioned magneto optics crystal perpendicularly with the aforementioned light beam. The 2nd wedge-like birefringence crystal to which the birefringence of the light beam outputted from the aforementioned magneto optics crystal is carried out.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] About an optical variable attenuator, a magneto optics crystal is used especially for this invention, and it relates to a small optical variable attenuator without a mechanical movable portion.
[0002]
[Description of the Prior Art] It is necessary to adjust optical intensity (power) if needed, therefore the optical variable attenuator is used in the optical transmission system. In the conventional variable attenuator, it adheres so that transmitted light intensity may change the matter continuously on a glass substrate, and the transparency position on a glass substrate is moved mechanically, and the magnitude of attenuation changes. since the conventional variable attenuator has mechanical structure, the configuration where a low and a speed of response are slow has large-sized reliability -- etc. -- it had the problem For this reason, it is difficult to include such an optical variable attenuator in transmission equipment, and has mainly been used as a measuring instrument.
[0003] In recent years, the technology of optical fiber amplifier progresses and it is becoming possible to amplify optical intensity comparatively simply. For this reason, examination of a wavelength multiplex communication system which makes the light of a large number from which wavelength differs transmit into one optical fiber is performed. The system configuration view of a typical wavelength multiplex communication system is shown in drawing 28 . If optical fiber amplifier is used, it will be possible to amplify collectively two or more lightwave signals by which wavelength multiplex was carried out, and construction of an economical optical transmission system will be attained.
[0004] The quality of a transmission signal is determined by the ratio (light SNR) of lightwave signal intensity and noise field intensity by the wavelength multiplex communication system which used optical fiber amplifier. In order to maintain the light SNR of each lightwave signal beyond a predetermined value, it is necessary to arrange the optical intensity of each lightwave signal. The level of each lightwave signal varies by dispersion in the output power of the light source (generally a laser diode (LD) is used), dispersion of the insertion loss of the various optical parts which it has for every light source, etc. Furthermore, if optical fiber amplifier also has the wavelength dependency of gain and passes optical fiber amplifier, the power of a lightwave signal will change for every wavelength. For this reason, it is necessary to incorporate the optical variable attenuator for adjusting and oppressing dispersion in the power of a lightwave signal in an optical transmission device.
[0005] JP,6-51255,A "an optical attenuator" is proposed as an optical variable attenuator for the above-mentioned purpose. The 1st example of composition of the conventional optical variable attenuator is shown in drawing 29 . This optical variable attenuator consists of a magneto optics crystal (magnetooptical cyristal) 1, a polarizer (polarizer) 2, the 1st magnetic field impression means 3 (the permanent magnet is used in this case) that impresses a magnetic field to a magneto optics crystal 1 at an optical axis and parallel, and the 2nd magnetic field impression means 4 which impresses a magnetic field to a magneto optics crystal 1 at an optical axis and a perpendicular. The Faraday-rotation child 9 consists of a magneto optics crystal 1, the 1st magnetic field impression means 3, and the 2nd magnetic field impression means 4. Here, a permanent magnet is used for the 1st magnetic field impression means 3, and the electromagnet which can adjust generating magnetic field strength by force current is used for the 2nd magnetic field impression means 4. Moreover, the light beam 5 of the linearly polarized light which passed other polarizers which are not illustrated passes a magneto optics crystal 1 and a polarizer 2 in the order.
[0006] In this optical variable attenuator, the synthetic vector (synthetic magnetic field) of the magnetic field vector generated with the 1st magnetic field impression means 3 and the magnetic field vector generated with the 2nd magnetic field impression means 4 is added to a magneto optics crystal 1. When the magnetic field vector generated with the 1st magnetic field impression means 3 is larger than a saturation magnetic field at this time, a synthetic vector also becomes larger than a saturation magnetic field. In this case, in a magneto optics crystal 1, an internal magnetic

domain will be substantially unified by one, and loss of the light beam 5 generated when a magneto optics crystal 1 has many magnetic domains will be reduced.
[0007] Force current's adjustment of the magnetic field strength of the 2nd magnetic field impression means 4 also changes the direction of a synthetic magnetic field according to force current. The polarization direction of a light beam 5 is rotated by the Faraday effect according to the strength of the component (magnetization vector) of the same direction as the light beam 5 of a synthetic magnetic field. Generally this Faraday-rotation angle theta is expressed with the following formula.
[0008]
Theta=V-L-H (1)
V is the number of Velde and is determined by the quality of the material of a magneto optics crystal 1. In L, the optical path length in a magneto optics crystal 1 and H show magnetic field strength. The light beam 5 which the polarization direction rotated by the magneto optics crystal 1 progresses to a polarizer 2. When the polarization direction in a polarizer 2 and the polarization direction of a light beam 5 are in agreement at this time, all the light beams 5 pass a polarizer 2. When both polarization direction is not in agreement, only the component of the polarization direction of the polarizer 2 of a light beam 5 passes. When it has the angle difference whose polarization direction of both is 90 degrees, a light beam 5 does not pass a polarizer 2, but the magnitude of attenuation serves as the maximum.
[0009] Moreover, other optical variable attenuators are shown in JP,6-51255,A "an optical attenuator." The 2nd example of composition of the conventional optical variable attenuator is shown in drawing 30 . The **** variable attenuator consists of optical fiber 6a, lens 7a, wedge-like birefringence crystal 8a, the Faraday-rotation child 9 that showed drawing 29 , wedge-like birefringence crystal 8b, lens 7b, and optical fiber 6b. In a **** variable attenuator, a part of light beam is led to optical fiber 6b using the birefringence by the birefringence crystals 8a and 8b of the light beam supplied from optical fiber 6a. Since the amount led to optical fiber 6b can be adjusted by the angle of rotation of the polarization direction of the light beam in the Faraday-rotation child 9, it can decrease the power of a light beam to adjustable.
[0010] Unlike the optical variable attenuator shown in drawing 29 , a **** variable attenuator can operate irrespective of the polarization direction of the light beam supplied from optical fiber 6a. The optical variable attenuator shown above does not have a mechanical movable portion, but can miniaturize it.
[0011]
[Problem(s) to be Solved by the Invention] However, there are the following troubles in the conventional optical variable attenuator using the magneto optics crystal mentioned above. In the 1st example of composition of the conventional optical variable attenuator shown in drawing 29 , the garnet thick film which generally has YIG and the Faraday effect is well used as a magneto optics crystal (Faraday cell) used for an optical variable attenuator. However, generally such a Faraday cell has the wavelength dependency and temperature dependence to angle of rotation. The wavelength dependency and temperature dependence of a Faraday-rotation angle of a Faraday cell are shown in Table 1.
[0012]
[Table 1]

項　目	ガーネット厚膜（一例）	YIG
波長依存性	−0.083 deg/nm	−0.040 deg/nm
温度依存性	−0.086 deg/nm	−0.042 deg/℃

[0013] Table 1 shows the change of a Faraday-rotation angle to change of wavelength in case the Faraday-rotation angle in 1550nm band is 45 degrees, and temperature. As for a garnet thick film, a property changes with the composition. The above-mentioned example shows the case of being comparatively large. The above-mentioned table 1 shows that a Faraday-rotation angle decreases, when wavelength or temperature increases.
[0014] Moreover, the relation between a magnetic field H and a Faraday-rotation angle is shown in drawing 31 . If a magnetic field H is increased in drawing 31 , a Faraday-rotation angle will incline, and will increase at VxL, and a Faraday-rotation angle will be saturated with the magnetic field more than a predetermined size. This shows that the magnetic domain inside a magneto optics crystal turned into a single magnetic domain. In drawing 31 , change of temperature or wavelength changes inclination VxL. This shows that a wavelength dependency and temperature dependence are in the number of Velde.
[0015] As mentioned above, there was a problem in which the temperature dependence and the wavelength

dependency of the magnitude of attenuation exist in the optical variable attenuator using the conventional magneto optics crystal. Furthermore, in order to include an optical variable attenuator in an optical transmission device, it is necessary to miniaturize the size of an optical variable attenuator further and to reduce drive current.

[0016] Moreover, in the 2nd example of composition of the conventional optical variable attenuator shown in drawing 31 , the loss (Polarization Dependent Loss:PDL) by few polarization dependencies has still arisen. In view of the above-mentioned trouble, the purpose of this invention reduces the temperature dependence, the wavelength dependency, and drive current of the magnitude of attenuation, and provides an optical transmission device with the small optical variable attenuator using the applicable magneto optics crystal easily.

[0017] The purpose of others of this invention reduces loss by the polarization dependency in the optical variable attenuator which used the wedge-like birefringence crystal.

[0018]

[Means for Solving the Problem] In order to solve the above-mentioned technical problem, in this invention, it is characterized by providing the following means. It is the optical variable attenuator which decreases the power of a light beam with invention equipment according to claim 1, and it has the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam, and the analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction, and it carries out that the polarization direction of the aforementioned analyzer is substantially set as a rectangular state with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal as the feature.

[0019] With invention equipment according to claim 2, in an optical variable attenuator according to claim 1, it has further the polarizer which generates the aforementioned light beam, and the polarization direction of the aforementioned analyzer is characterized by being set as a rectangular state as substantially as the polarization direction of the aforementioned polarizer.

[0020] With invention equipment according to claim 3, the polarization direction of the aforementioned analyzer and the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal are characterized by being set up at the angle of **30 degrees 80 degrees in an optical variable attenuator according to claim 1 or 2.

[0021] The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 4, The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal, It is prepared in either the interior of the aforementioned magnetic circuit, or near, and has the permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal in parallel. Even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost, it is characterized by impressing a magnetic field to the aforementioned magneto optics crystal, and penetrating a part of aforementioned light beam [at least].

[0022] The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 5, The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal, It has the permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal at an angle smaller than 90 degrees. Even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost, it is characterized by impressing a magnetic field to the aforementioned magneto optics crystal, and penetrating a part of aforementioned light beam [at least].

[0023] With invention equipment according to claim 6, in an optical variable attenuator according to claim 4 or 5, it has further the analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction, and the polarization direction of the aforementioned analyzer is characterized by being substantially set as a rectangular state with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal.

[0024] With invention equipment according to claim 7, it is the optical variable attenuator which decreases the power of a light beam, and the magnetic field for being impressed by the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam, and the aforementioned magneto optics crystal is generated, it has the magnetic circuit which has the yoke with which the aforementioned magneto optics crystal was inserted in the internal gap, and the magnetic field generated in the yoke of the aforementioned magnetic circuit is characterized by being efficiently impressed by the aforementioned magneto optics crystal.

[0025] With invention equipment according to claim 8, the aforementioned magnetic circuit is characterized by having further at least one coil for being prepared near the gap of the aforementioned yoke and making the aforementioned gap generate a magnetic field electrically in an optical variable attenuator according to claim 7.
[0026] With invention equipment according to claim 9, in an optical variable attenuator according to claim 7, it has further the 1st lens for converging the aforementioned light beam and carrying out incidence to the aforementioned magneto optics crystal, the interval of the gap of the aforementioned yoke is narrowed according to the size of the light beam which it converged with the 1st lens of the above, and it is characterized by impressing efficiently the magnetic field generated about this gap to the aforementioned magneto optics crystal.
[0027] With invention equipment according to claim 10, in an optical variable attenuator according to claim 9, after the light beam by which convergence was carried out [aforementioned] passes the aforementioned magneto optics crystal, it is characterized by including the 2nd lens for setting the light beam by which convergence was carried out [aforementioned] as a predetermined size.
[0028] The light amplifier which has the gain property which is the light amplifier which amplifies the lightwave signal which has a predetermined wavelength-range region with invention equipment according to claim 11, and has a wavelength dependency, This lightwave signal is decreased in adjustable using rotation of the polarization direction of the lightwave signal in a magneto optics crystal. While a damping property has the aforementioned wavelength dependency of the gain in the aforementioned light amplifier, and the optical variable attenuator which has a reverse wavelength dependency substantially and the aforementioned lightwave signal decreases it in the aforementioned optical variable attenuator, it is characterized by reducing the aforementioned wavelength dependency of the gain in the aforementioned light amplifier.
[0029] With invention equipment according to claim 12, it sets to light amplifier according to claim 11. the aforementioned optical variable attenuator It has the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned lightwave signal, and the analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction. The polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal are characterized by being set up so that the wavelength dependency of the aforementioned reverse may be acquired substantially in the predetermined magnitude of attenuation.
[0030] The magneto optics crystal which it is [magneto optics crystal] an optical variable attenuator for connecting with a light amplifier, and reducing the wavelength dependency of the gain in the aforementioned light amplifier with invention equipment according to claim 13, and decreasing a lightwave signal, and makes adjustable rotate the polarization direction of the aforementioned lightwave signal, It has the analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction. the polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal In the predetermined magnitude of attenuation, it is characterized by being set up so that a reverse wavelength dependency may be substantially acquired with the wavelength dependency of the gain of the aforementioned light amplifier.
[0031] The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 14, The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator, It is characterized by controlling the polarization direction of the aforementioned light beam in the aforementioned magneto optics crystal so that it may have the output side electric eye which branches a part of output light of the aforementioned optical variable attenuator, and carries out the monitor of the output power and the output power of the aforementioned optical variable attenuator which carried out the monitor by the aforementioned output side electric eye may become a predetermined value.
[0032] The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 15, The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator, The input-side electric eye which carries out the monitor of the input control power of the light beam inputted into the aforementioned magneto optics crystal, So that it may have the output side electric eye which carries out the monitor of the output power of the aforementioned optical variable attenuator and a ratio with the output power of the aforementioned optical variable attenuator which carried out the monitor by the input control power and the aforementioned output side electric eye of the aforementioned light beam which carried out the monitor by the aforementioned input-side electric eye may become a predetermined value It is characterized by controlling the polarization direction of the

aforementioned light beam in the aforementioned magneto optics crystal.
[0033] invention equipment according to claim 16 -- an optical variable attenuator according to claim 14 or 15 -- setting -- the aforementioned analyzer -- a birefringence crystal -- containing -- the aforementioned analyzer **** -- it is characterized by having further the aperture which leads a part of light beam from which polarization was separated to the aforementioned output side electric eye
[0034] The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 17, The magnetic circuit which generates the magnetic field for being impressed by the aforementioned magneto optics crystal about an internal gap, It has a case for holding the aforementioned magneto optics crystal and the aforementioned magnetic circuit, and mounting in a substrate, and the aforementioned magnetic circuit is characterized by being mounted in a case so that the direction of the aforementioned gap may be the height direction of the aforementioned case substantially.
[0035] It is the optical variable attenuator which decreases the power of a light beam with invention equipment according to claim 18, it is the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam, and the magnetic circuit which generates the magnetic field for being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and it carries out having the aforementioned magnetic circuit which is close so that the aforementioned point may sandwich the aforementioned magneto optics crystal including the yoke of a horseshoe-shape configuration with which the front point is thinner than other portions as the feature.
[0036] With invention equipment according to claim 19, in an optical variable attenuator according to claim 18, the aforementioned magnetic circuit consists of permanent magnets, and it has further the electromagnet which generates electrically the magnetic field for being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and the point of the yoke of the aforementioned permanent magnet is characterized by being close from the aforementioned electromagnet with the aforementioned magneto optics crystal.
[0037] Even if it is the optical variable attenuator which decreases the power of a light beam, it has the magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam, and the magnetic circuit which generates electrically the magnetic field for having the yoke which contains the half-hard magnetic substance in part at least, and being impressed by the aforementioned magneto optics crystal by drive current with invention equipment according to claim 20 and supply of the aforementioned drive current stops, it carries out that the aforementioned magnetic field is maintained as the feature.
[0038] With invention equipment according to claim 21, in an optical variable attenuator according to claim 20, the aforementioned yoke has partially two or more half-hard magnetic substance with which the magnetization in a saturation state differs, and is characterized by the ability to change gradually the size of the magnetic field generated in the aforementioned magnetic circuit by controlling magnetization for every aforementioned half hard magnetic substance.
[0039] The 1st wedge-like birefringence crystal to which it is the optical variable attenuator which decreases the power of a light beam, and the birefringence of the aforementioned light beam is carried out with invention equipment according to claim 22, The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam where polarization was separated as the wedge-like birefringence crystal of the above 1st, The magnetic circuit which generates the magnetic field for being substantially impressed by the aforementioned magneto optics crystal perpendicularly with the aforementioned light beam, It has the 2nd wedge-like birefringence crystal to which the birefringence of the light beam outputted from the aforementioned magneto optics crystal is carried out. It is characterized by impressing the magnetic field of the aforementioned magnetic circuit to the flat surface which consists of aforementioned light beams from which polarization was separated as the wedge-like birefringence crystal of the above 1st perpendicularly substantially at the aforementioned magneto optics crystal.
[0040] Above invention equipment acts as follows. In the optical variable attenuator given in any 1 term, the polarization direction of the aforementioned analyzer is substantially set as the rectangular state with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal a claim 1 or among 3.
[0041] In this case, when a Faraday-rotation angle is large, the variation of a Faraday-rotation angle to change of wavelength is also large. However, since the variation of the magnitude of attenuation to change of a Faraday-rotation angle is small, the variation of the magnitude of attenuation to change of wavelength can be reduced. Moreover, when a Faraday-rotation angle is small, the variation of a Faraday-rotation angle to change of wavelength is also small. Therefore, in this case, although the variation of the receiving magnitude of attenuation to change of a Faraday-rotation

angle is large, the variation of the magnitude of attenuation to change of wavelength can be reduced.
[0042] Therefore, the wavelength dependency of the magnitude of attenuation can be reduced in a **** variable attenuator. Moreover, the temperature dependence of the magnitude of attenuation can be reduced similarly. In the optical variable attenuator given in any 1 term, the magnetic field generated with the permanent magnet or its part is always impressed to a light beam and parallel at the magneto optics crystal a claim 4 or among 6. Therefore, in a **** variable attenuator, even if the current impressed to a magnetic circuit will not flow by failure etc., a light beam can be penetrated. Consequently, the influence which it has on operation of transmission equipment can be reduced. Furthermore, wavelength and temperature dependence can also be reduced.
[0043] Especially, at an optical variable attenuator according to claim 5, an above-mentioned effect can be acquired with simpler composition. In an optical variable attenuator given in any 1 term, a magneto optics crystal (Faraday cell) can be inserted without a crevice into the gap of a yoke a claim 7 or among 10. Therefore, the magnetic field generated in the yoke can be efficiently supplied to a magneto optics crystal, without leaking outside, consequently can impress uniformly a magnetic field strong against a magneto optics crystal. Therefore, the current supplied at a magnetic circuit compared with composition with a crevice between a magneto optics crystal and a yoke can be reduced, and the drive power of a magnetic circuit can be reduced.
[0044] Especially, in an optical variable attenuator according to claim 8, by preparing the coil near the magneto optics crystal, the influence of the magnetic reluctance in a yoke is reduced, and the magnetic field efficiently generated in the yoke can be supplied to a magneto optics crystal. Therefore, the drive power of an electromagnet can be reduced more. Furthermore, since the height by the side of the loop of a yoke can be made low, the height of an optical variable attenuator can also be made low, consequently the ease of mounting improves.
[0045] Moreover, in an optical variable attenuator according to claim 9 or 10, the interval of the gap of a yoke can be narrowed to about 200 micrometers. Therefore, the magnetic field generated in the yoke can be efficiently impressed to a Faraday cell, and drive power can be reduced further.
[0046] In light amplifier according to claim 11 or 12 and an optical variable attenuator according to claim 13, the wavelength dependency of the magnitude of attenuation can be arbitrarily set up by adjusting the polarization direction of an analyzer, the polarization direction of a lightwave signal, and a magneto optics crystal. Therefore, the wavelength dependency of the gain of a light amplifier can be reduced without using the light filter for gain equalization. Moreover, in a **** variable attenuator, a wavelength dependency is greatly made, so that the magnitude of attenuation is large. Therefore, the wavelength dependency of the gain of a light amplifier when the upper limit of optical-pumping power is small is cancellable good. Therefore, the power of the excitation light of optical fiber amplifier can be set up small, and the miniaturization of optical fiber amplifier and low-power-ization are attained.
[0047] A claim 14 or among 16, it is controlled, or it is controlled so that a ratio with the output power of the optical variable attenuator which carried out the monitor by the power and the output side electric eye of the light beam which carried out the monitor by the input-side electric eye becomes a predetermined value so that the output-power power of the optical variable attenuator which carried out the monitor by the output side electric eye in the optical variable attenuator given in any 1 term becomes a predetermined value. Therefore, amendment of the temperature characteristic of the magnitude of attenuation of an optical variable attenuator, degradation with the passage of time, polarization loss change, etc. is attained.
[0048] What is necessary is just to secure the space which is equivalent to the radius of a ring-like yoke, respectively to light beam a top and the bottom in an optical variable attenuator according to claim 17, if a magnetic circuit is constituted from a ring-like yoke. Therefore, the height of an optical variable attenuator can be made low.
[0049] In an optical variable attenuator according to claim 18 or 19, the magnetic field of a magnetic circuit can be efficiently impressed to a magneto optics crystal. Therefore, a magnetic circuit can prevent revealing a magnetic field outside, and can also reduce the influence of the magnet on others. In an optical variable attenuator according to claim 20, a yoke contains the half-hard magnetic substance in part at least. Therefore, a yoke is magnetized by impression of a pulse current, and the magnetization is held even if it stops supply of current. Therefore, the power consumption of an optical variable attenuator can be reduced.
[0050] In an optical variable attenuator according to claim 21, the magnetic field generated with an electromagnet can be stably set up gradually by controlling two or more half-hard magnetic substance with which magnetization differs. In an optical variable attenuator according to claim 22, the bias magnetic field for simplifying the magnetic domain of a magneto optics crystal is substantially impressed perpendicularly by the refraction flat surface. Thereby, polarization dependency loss can be reduced.
[0051]
[Embodiments of the Invention] First, the 1st principle of this invention is explained. Drawing 1 is the example of composition of the optical variable attenuator concerning this invention. this -- light -- a variable attenuator -- a

polarizer -- (-- P --) -- ten -- a magneto optics crystal -- it is -- a Faraday cell -- (-- FR --) -- 20 -- and -- an analyzer (analyzer) -- (-- A --) -- 30 -- constituting -- having . A light beam 5 is supplied in order of a polarizer 10, Faraday cell 20, and an analyzer 30.

[0052] Moreover, the optical variable attenuator has further the permanent magnet 40 for impressing a magnetic field to Faraday cell 20, and the electromagnet 50 which consists of a yoke 52 and a coil 54. The magnetic field by the permanent magnet 40 is impressed in the direction of a light beam 5, and the perpendicular direction at Faraday cell 20, and the magnetic field by the electromagnet 50 is impressed in the direction of a light beam 5, and the same direction at Faraday cell 20.

[0053] If a light beam 5 is supplied to a polarizer 10, the light of the linearly polarized light which has the same polarization direction as the polarization direction of a polarizer 10 will be outputted. The light of this linearly polarized light passes Faraday cell 20, and the polarization direction of passage light is rotated by the Faraday effect according to the magnetization magnitude of a vector generated in the direction of a light beam 5 at this time. The light beam 5 which the polarization direction rotated is supplied to an analyzer 30.

[0054] The magnetic field by the permanent magnet 40 is large enough to the extent that it simplifies the magnetic domain in Faraday cell 20. Therefore, also in the synthetic magnetic field of a permanent magnet 40 and an electromagnet 50, loss of the light beam 5 within Faraday cell 20 sufficiently enlarges very few. The size of the magnetic field of an electromagnet 50 can change with the current impressed to a coil 54, and the direction of a synthetic magnetic field can also change with them. At this time, the polarization direction of a light beam 5 is rotated by the component (magnetization vector) of the same direction as the light beam 5 of the synthetic magnetic fields by the Faraday effect. When the polarization direction of a light beam 5 rotated by the Faraday effect is not in agreement with the polarization direction of an analyzer 30, a part or all of a light beam 5 is intercepted by the analyzer 30, and a light beam 5 declines.

[0055] The above operation is substantially [as operation of the optical variable attenuator using the conventional magneto optics crystal] the same. Further, the polarizer 10 and the analyzer 30 consist of this inventions so that the polarization direction of the light beam 5 in the state (the magnetic field of the direction of an optical axis is zero) where there is no Faraday rotation in Faraday cell 20 may be in a rectangular state mostly with the polarization direction of an analyzer 30. Thereby, the temperature dependence and the wavelength dependency of the magnitude of attenuation of an optical variable attenuator can be reduced. Moreover, the above-mentioned rectangular state can insert a wavelength plate (polarization can be rotated) into an optical path, and can set it up also by adjusting arrangement of a polarizer and an analyzer. For example, even if it sets a polarizer and an analyzer as arrangement 0 times, they can set up arrangement 90 degrees substantially by inserting a wavelength plate and rotating polarization 90 degrees.

[0056] A principle and operation are explained below. By the conventional optical variable attenuator, although it can be set as any value, the angle difference of the polarization direction of a polarizer 10 and the polarization direction of an analyzer 30 examines three kinds of angle differences (arrangement) in order to simplify explanation here. The example of arrangement of a polarizer (P), a Faraday cell (FR), and an analyzer (A) is shown in drawing 2 . (A) of drawing 2 is the case where call arrangement 0 times, (B) of drawing 2 calls arrangement 45 degrees when the polarization direction of a polarizer and the polarization direction of an analyzer are parallel, (C) of drawing 2 calls arrangement 90 degrees when the angle difference of the polarization direction of a polarizer and the polarization direction of an analyzer is 45 degrees, and the polarization direction of a polarizer and the polarization direction of an analyzer lie at right angles. The arrangement shown in (C) of drawing 2 is applied to the optical variable attenuator concerning this invention.

[0057] The magnitude of attenuation A of an optical variable attenuator is shown by the following formulas when the relative angle of the polarization direction of light and the polarization direction of a sensor which were rotated by the Faraday cell is set to theta.

A=10 log(cos2 (90-theta+E))+Lo (2)

E: An extinction ratio (anti-logarithm), Lo : loss (dB)

Here, the extinction ratio of the optic from which E constitutes an optical variable attenuator, and Lo are the internal losses of an optic. By this formula, the magnitude of attenuation A of an optical variable attenuator is cos2. It increases according to theta. The calculation result of the magnitude of attenuation to the Faraday-rotation angle in 0 times arrangement is shown in drawing 3 . The calculation result of the magnitude of attenuation to the Faraday-rotation angle in 45-degree arrangement is shown in drawing 4 . The calculation result of the magnitude of attenuation to the Faraday-rotation angle in 90-degree arrangement is shown in drawing 5 . In the above-mentioned drawing, it is Control about a Faraday-rotation angle. Angle (deg) is called.

[0058] In 0 times arrangement of (A), when a Faraday-rotation angle is 0 times (an impression magnetic field is zero),

the magnitude of attenuation is the smallest and the magnitude of attenuation serves as the maximum in the Faraday-rotation [which increases a Faraday-rotation angle] angle which it is alike, therefore the magnitude of attenuation increases, and is 90 degrees. In this case, to the Faraday-rotation angle to near 20 degrees, change of the magnitude of attenuation is loose, and change of the magnitude of attenuation [as opposed to angle of rotation at the Faraday-rotation angle near 90 degrees] is large. In order to attain the above-mentioned control, the length which can be rotated 90 degrees or more is required for length L of a Faraday cell.
[0059] In 45-degree arrangement of (B), when a Faraday-rotation angle is 0 times (an impression magnetic field is zero), the magnitude of attenuation is 3dB. If an angle of rotation is set as -45 degrees, the magnitude of attenuation will serve as the minimum, and if it is set as +45 degrees, the magnitude of attenuation will serve as the maximum. In this case, change of the magnitude of attenuation [as opposed to angle of rotation at the Faraday-rotation angle near 45 degrees] is large. In the above-mentioned control, Faraday rotation of an opposite direction can be obtained by impressing the current of a retrose. Therefore, length L of a Faraday cell is good by the length which can be rotated 45 degrees or more. Therefore, it is good in the half of the length of the Faraday cell in (A).
[0060] In 90-degree arrangement of (C), when a Faraday-rotation angle is 0 times (an impression magnetic field is zero), the magnitude of attenuation is the largest and the magnitude of attenuation serves as the minimum in the Faraday-rotation [which increases a Faraday-rotation angle] angle which it is alike, therefore the magnitude of attenuation decreases, and is 90 degrees. In this case, change of the magnitude of attenuation [as opposed to an angle of rotation to the Faraday-rotation angle near 0 times] is large, and change of the magnitude of attenuation [as opposed to angle of rotation at the Faraday-rotation angle near 90 degrees] is small. In order to attain the above-mentioned control, the length which can be rotated 90 degrees or more is required for length L of a Faraday cell.
[0061] As shown in the above explanation, near the maximum magnitude of attenuation, a rapid change of the magnitude of attenuation arises in change of few Faraday-rotation angles. However, examination showed that the variation of a Faraday-rotation angle to change of wavelength or temperature was dependent on a Faraday-rotation angle. Drawing 6 is a typical related view with the variation of a Faraday-rotation angle to change of a Faraday-rotation angle, wavelength, or temperature. The variation of a Faraday-rotation angle is proportional to a Faraday-rotation angle. that is, when a Faraday-rotation angle is 0 times (an impression magnetic field is zero), the variation of the Faraday-rotation angle by change of wavelength or temperature is zero, and a Faraday-rotation angle increases it -- it is alike, and it follows and the variation of a Faraday-rotation angle also increases
[0062] Therefore, in the state (state where a component parallel to the light beam of the synthetic magnetic field of two magnets serves as zero substantially) where Faraday rotation does not occur, the variation of the Faraday-rotation angle by change of wavelength or temperature is the minimum (substantially zero), and it is in this state, and if a polarizer and an analyzer are arranged so that the maximum magnitude of attenuation may be obtained, change of the magnitude of attenuation to change of a Faraday-rotation angle will also become small. Therefore, the temperature dependence and the wavelength dependency of the magnitude of attenuation are mitigable. Such arrangement is equivalent to the above-mentioned 90-degree arrangement of (C).
[0063] That is, the maximum magnitude of attenuation with the variation of the magnitude of attenuation to a Faraday-rotation angle large when the Faraday-rotation angle from which the variation of the Faraday-rotation angle by change of wavelength or temperature serves as the minimum is nullity is obtained, and when it is the large Faraday-rotation angle to which the variation of a Faraday-rotation angle becomes large, the small magnitude of attenuation which shows change of the loose magnitude of attenuation is obtained.
[0064] Specifically, when a Faraday-rotation angle is 0 times, arrangement of the polarization direction of a polarizer and the polarization direction of an analyzer is set as 90 degrees so that the maximum attenuation may be obtained. In this case, to change of a Faraday-rotation angle, although a Faraday-rotation angle changes with change of temperature or wavelength a lot at the time of the maximum transparency to which a Faraday-rotation angle becomes 90 degrees, since change of the magnitude of attenuation is very loose, change of the magnitude of attenuation can do very small at the time of the maximum transparency.
[0065] The feature in 0 times arrangement of a polarizer and an analyzer, 45-degree arrangement, and 90-degree arrangement is shown in Table 2.
[0066]
[Table 2]

P．A 配置	電流零時 の減衰量	電流と 減衰量 の関係	駆動電 流方向	駆動 電流値 比率	FR素子 の厚さ 比率	波長・ 温度 依存性	入出力 ポートの 区別
0度	最小減衰	流すと 減衰	単極性	1	1	大	なし 同一動作
45度	1/2 減衰	極性に 依存	両極性	±1/2	1／2	中	あり 相補動作
90度	最大減衰	流すと 透過	単極性	－1	1	小	なし 同一動作

[0067] In 0 times arrangement and 90-degree arrangement, there is no distinction of input/output port. Even if it inputs [either], the same damping property can be acquired. On the other hand, in 45-degree arrangement, non-repulsion-operation will be performed if input/output port is replaced. Although it becomes 3dB attenuation even if it inputs [either] when current is 0, when making the light beam penetrate by no decreasing from one side, it becomes the maximum attenuation from opposite direction. That is, it operates as an isolator.
[0068] Moreover, the damping property over wavelength in case the angle differences of the polarization direction of a polarizer and an analyzer are 0 times, 45 degrees, 70 degrees, 80 degrees, and 90 degrees, respectively is shown in drawing 11 from drawing 7 . (A) of each drawing shows change of the arbitrary magnitude of attenuation to wavelength, and (B) of each drawing shows the deflection of the arbitrary magnitude of attenuation to wavelength. At (B), deflection is normalized on the wavelength of 1545nm.
[0069] When obtaining the magnitude of attenuation 20dB or more in 0 times arrangement of drawing 7 , the deflection of the magnitude of attenuation to wavelength is large. On the other hand, the deflection of the magnitude of attenuation [as opposed to / as opposed to / the magnitude of attenuation 35dB or more / by 90 degree arrangement of drawing 11] wavelength / is very small. Moreover, when the magnitude of attenuation is 1dB, a Faraday-rotation angle is large, for example, change of a Faraday-rotation angle becomes about **2.5 degrees to **15nm wavelength variation. However, as shown by (B) of drawing 11 , the deflection of the magnitude of attenuation at that time is **0.01dB or less, and influence does not give operation of an optical transmission.
[0070] When applying an optical variable attenuator to an optical transmission device, generally the 0-20dB magnitude of attenuation is often used. Therefore, when the deflection to the 0-20dB magnitude of attenuation was calculated, it turns out that the deflection in the 80-degree arrangement shown in drawing 10 is the smallest. Furthermore, if a general service condition is taken into consideration, the angle difference of the polarization direction of an analyzer and a polarizer can fully reduce a wavelength dependency practically, if it arranges within the limits of about **30 degrees 80 degrees.
[0071] Therefore, a polarizer and an analyzer consist of optical variable attenuators of this invention in drawing 1 so that the polarization direction of the light beam 5 in the state where there is no Faraday rotation in Faraday cell 20 may be in a rectangular state mostly with the polarization direction of an analyzer. Furthermore, as for the angle difference of the polarization direction of a polarizer and an analyzer, it is desirable that it is [80 degree] **30 degrees.
[0072] this invention is applicable to other examples of composition of an optical variable attenuator besides the example of composition shown in drawing 1 . Drawing 12 is other examples of composition of the optical variable attenuator concerning this invention. This optical variable attenuator consists of a polarizer 10, Faraday cell 20, and an analyzer 30 like the optical variable attenuator of drawing 1 . Furthermore, the polarizer 10 and the analyzer 30 are arranged so that each polarization direction may be in a rectangular state mostly. Here, in order to simplify explanation, the difference of the polarization direction is made into 90 degrees.
[0073] The optical variable attenuator shown in drawing 12 has further the permanent magnet 42 for impressing a magnetic field to Faraday cell 20, and the electromagnet 55 which consists of a yoke 57 and a coil 59. The permanent magnet 42 consists of two magnets which have a doughnut-like hole, and a light beam 5 passes through a hole. The magnetic field by the permanent magnet 42 is impressed in the direction of a light beam 5, and the parallel direction at Faraday cell 20, and the magnetic field by the electromagnet 55 is impressed in the direction of a light beam 5, and the perpendicular direction at Faraday cell 20.
[0074] The light beam 5 which has the linearly polarized light outputted from the polarizer 10 passes Faraday cell 20 through the hole of a permanent magnet 42. The light beam 5 to which Faraday rotation of the polarization direction was carried out is supplied to an analyzer 30 through the hole of the permanent magnet 42 of further others. The magnetic field by the permanent magnet 42 is large enough to the extent that it simplifies the magnetic domain in

Faraday cell 20. Therefore, also in the synthetic magnetic field of a permanent magnet 42 and an electromagnet 55, loss of the light beam 5 within Faraday cell 20 sufficiently enlarges very few.

[0075] In this optical variable attenuator, if the current impressed to a coil 59 is made into zero, the magnetic field of a permanent magnet 42 will start only in the direction of a light beam 5. At this time, Faraday rotation of the polarization direction of a light beam 5 is carried out greatly, and when a Faraday-rotation angle is 90 degrees, the magnitude of attenuation serves as the minimum. On the other hand, if the current impressed to a coil 59 is increased, the magnetization vector of the direction of a light beam 5 will decrease, and a Faraday-rotation angle will also decrease. As for the magnitude of attenuation, a Faraday-rotation angle serves as the maximum substantially at the time of 0 times (when the direction of the synthetic magnetic field of a permanent magnet 42 and an electromagnet 55 becomes perpendicular substantially with the direction of a light beam 5). The relation between a Faraday-rotation angle and the magnitude of attenuation is the same as the relation shown in drawing 5 .

[0076] When a Faraday-rotation angle is large, the variation of a Faraday-rotation angle to change of wavelength is also large. However, as shown in drawing 5 in this case, the variation of the magnitude of attenuation to change of a Faraday-rotation angle is small. Therefore, the variation of the magnitude of attenuation to change of wavelength can be reduced.

[0077] Moreover, when a Faraday-rotation angle is small, the variation of a Faraday-rotation angle to change of wavelength is also small. Therefore, in this case, although the variation of the receiving magnitude of attenuation to change of a Faraday-rotation angle is large, the variation of the magnitude of attenuation to change of wavelength can be reduced. In a **** variable attenuator, the variation of the magnitude of attenuation can be similarly reduced to a temperature change. Moreover, when applying this optical variable attenuator to an optical transmission device, the angle difference of the polarization direction of a polarizer and an analyzer has 80 desirable degrees [**30] like the optical variable attenuator shown in drawing 1 .

[0078] In addition, arrangement of the polarization direction of the polarizer in the optical variable attenuator concerning this invention and an analyzer is applicable to the composition of various magnetic circuits irrespective of arrangement of a magnetic circuit. Next, the 2nd principle of the optical variable attenuator concerning this invention is explained. In the optical variable attenuator concerning this invention, when the current impressed to an electromagnet is zero, it always changes an optical variable attenuator into a transparency state.

[0079] Although 90-degree arrangement of the polarizer mentioned above and an analyzer can make a wavelength dependency and temperature dependence very small, when the current (drive current) impressed to the coil 54 of an electromagnet 50 is zero in the composition of the magnetic circuit (a permanent magnet 40 and electromagnet 50) of an optical variable attenuator shown in drawing 1 , the magnitude of attenuation serves as the maximum. When drive current goes out by failure of a control circuit etc., the magnitude of attenuation serves as the maximum automatically, and this serves as a fail-safe function. However, since light does not penetrate conversely, there is a possibility of affecting an equipment assembly. There are more latter faults practical.

[0080] Drawing 13 is drawing for explaining the 2nd principle of the optical variable attenuator concerning this invention. Compared with the optical variable attenuator which shows the optical variable attenuator shown in drawing 13 to drawing 1 , the electromagnet 60 is formed instead of the electromagnet 50. The electromagnet 60 consists of the yokes 62 and coils 64 having a permanent magnet 66. Moreover, the permanent magnet 40 is omitted on account of explanation. Other composition is the same as the optical variable attenuator of drawing 1 . Therefore, the polarizer 10 and the analyzer 30 are installed so that the angle difference of those polarization directions may be 90 degrees. The same reference number is given to the element which has the same function as the optical variable attenuator of drawing 1 .

[0081] In the optical variable attenuator of drawing 13 , a bias magnetic field is impressed in the direction of a light beam 5 with the permanent magnet 66 in an electromagnet 60. This bias magnetic field strength is set up so that the Faraday-rotation angle in Faraday cell 20 may be 90 degrees. Furthermore, the magnetic field of the electromagnet 60 generated when current is impressed to a coil 64 operates so that the bias magnetic field of a permanent magnet 66 may be negated.

[0082] In this optical variable attenuator, when the current impressed to a coil 64 is zero, with a permanent magnet 66, only a bias magnetic field is impressed in the direction of a light beam 5, and the polarization direction of a light beam 5 is rotated 90 degrees in Faraday cell 20. Therefore, as for the rotated polarization direction of a light beam 5, in accordance with the polarization direction of an analyzer 30, the permeability of an optical variable attenuator serves as the maximum. On the other hand, if the current impressed to a coil 64 increases, a bias magnetic field will be negated, and Faraday rotation will decrease, consequently the magnitude of attenuation will increase.

[0083] Therefore, at a **** variable attenuator, by failure etc., even if the current impressed to an electromagnet 60 will not flow, a light beam can be penetrated and wavelength and temperature dependence can also be reduced. The

example of change of an optical variable attenuator shown in drawing 14 at drawing 13 is shown. In the optical variable attenuator shown in drawing 14 , Faraday cell 22 which has the length of the half is formed instead of Faraday cell 20 compared with the optical variable attenuator shown in drawing 13 . The length of Faraday cell 22 is chosen by the bias magnetic field of the permanent magnet 66 in an electromagnet 60 so that -45 Faraday rotation may be performed. Other composition is the same as the optical variable attenuator of drawing 13 . Therefore, the polarizer 10 and the analyzer 30 are installed so that the angle difference of those polarization directions may be 90 degrees. The same reference number is given to the element which has the same function as the optical variable attenuator of drawing 13 .

[0084] In this optical variable attenuator, when the current impressed to an electromagnet 60 is zero, only the bias magnetic field by the permanent magnet 66 is impressed to Faraday cell 22, and -45 Faraday rotation is performed. At this time, permeability is about 50%. If current is impressed to an electromagnet 60 in the right direction, a bias magnetic field will decrease by the magnetic field by the electromagnet 60, and a Faraday-rotation angle will also decrease. When a Faraday-rotation angle is 0 times, the magnitude of attenuation serves as the maximum.

[0085] On the other hand, if current is impressed to an electromagnet 60 in the negative direction, the magnetic field by the electromagnet 60 will join a bias magnetic field, and a Faraday-rotation angle will increase in the negative direction. When a Faraday-rotation angle becomes -90 degrees, permeability serves as the maximum. Therefore, also in a **** variable attenuator, by failure etc., even if the current impressed to an electromagnet 60 will not flow, a light beam can be penetrated about 50%, and wavelength and temperature dependence can also be reduced. Furthermore, since a Faraday-rotation angle is small made at 45 degrees, the power supplied to an electromagnet can be reduced and low-power-ization of an optical variable attenuator can also be attained.

[0086] In above-mentioned drawing 13 and the optical variable attenuator of drawing 14 , the structure which embeds a permanent magnet into a yoke is illustrated. However, since the permeability of the material of a yoke is very high, it can make a permanent magnet only able to approach a yoke, and can acquire the same effect. The example of change of an optical variable attenuator shown in drawing 15 at drawing 14 is shown. In the optical variable attenuator shown in drawing 15 , compared with the optical variable attenuator shown in drawing 14 , the electromagnet 50 which does not contain a permanent magnet instead of an electromagnet 60 is formed, and the permanent magnet 70 for adding a bias magnetic field to Faraday cell 22 from the direction of slanting is formed further. Other composition is the same as the optical variable attenuator of drawing 14 . The same reference number is given to the element which has the same function as the optical variable attenuator of drawing 14 .

[0087] In the optical variable attenuator of above-mentioned drawing 14 , the bias magnetic field is added in parallel with a light beam 5 with the permanent magnet 66 prepared in the yoke 62. In this case, in order to simplify the magnetic domain in Faraday cell 22, a bias magnetic field can be further added in the direction perpendicular to a light beam 5 with another permanent magnet like the optical variable attenuator of drawing 1 . At this time, the synthetic magnetic field by which vector composition of these bias magnetic fields was carried out is added to Faraday cell 22. In the optical variable attenuator shown in drawing 15 , this synthetic magnetic field can be formed with one permanent magnet 70.

[0088] Therefore, a **** variable attenuator is simpler composition and can have the same effect as the optical variable attenuator shown in drawing 14 . Moreover, this invention is applicable not only to the optical variable attenuator shown in drawing 14 but other examples of composition containing the optical variable attenuator of drawing 13 . Next, the 3rd principle of the optical variable attenuator concerning this invention is explained. When including an optical variable attenuator in equipment, in order to attain low-power-ization of equipment, it is necessary to reduce the drive power impressed to the coil of the magnetic circuit which controls the magnitude of attenuation of an optical variable attenuator. For that purpose, it is necessary to impress efficiently the magnetic field generated in the magnetic circuit to a Faraday cell.

[0089] Drawing 16 is the example of composition of the magnetic circuit of the optical variable attenuator concerning this invention. The electromagnet 80 which consists of a yoke 82 and a coil 84, and Faraday cell 20 are shown by drawing 16 . Faraday cell 20 is inserted that there is no crevice in the gap of a yoke 82. Therefore, the magnetic field generated in the yoke 82 can be efficiently supplied to Faraday cell 20, without leaking outside, consequently can impress a magnetic field strong against a Faraday cell uniformly. Therefore, the current supplied at a coil compared with composition with a crevice between a Faraday cell and a yoke can be reduced, and the drive power of an electromagnet can be reduced.

[0090] Drawing 17 is the example of change of the magnetic circuit of an optical variable attenuator shown in drawing 16 . The cross section which looked at (A) from the top, and (B) show the cross section seen from width. In the magnetic circuit of the optical variable attenuator of drawing 17 , two divided coils 86-1 and 86-2 are prepared near Faraday cell 20 instead of the coil 84 compared with the electromagnet 80 shown in drawing 16 .

[0091] By preparing the coil near Faraday cell 20, the influence of the magnetic reluctance in a yoke is reduced, and the magnetic field efficiently generated in the yoke can be supplied to Faraday cell 20. The drive power of an electromagnet can be reduced also by this composition. Furthermore, since the height by the side of the loop of a yoke 82 can be made low, the height of an optical variable attenuator can also be made low, consequently the ease of mounting improves.

[0092] In addition, in the optical variable attenuator shown in drawing 17 , the wedge-like birefringence crystal is used as a polarizer and an analyzer, and, thereby, a polarization dependency can be removed. This operation is indicated by JP,6-51255,A "an optical attenuator." The following methods are also considered as a method of impressing efficiently the magnetic field generated in the yoke to a Faraday cell. In the magnetic circuit of drawing 16 and drawing 17 , the gap of the yoke which inserts a Faraday cell can impress a magnetic field to a Faraday cell efficiently, so that it is narrow. Since it is not large compared with it of a yoke, the relative permeability of a Faraday cell has a possibility that a stray magnetic field may occur all over space through a Faraday cell.

[0093] For this reason, it is necessary to keep the gap of a yoke as narrow as possible. If a gap is narrowed, in order for the area which a light beam penetrates to decrease, it is necessary to make small the collimated light beam system. This demand can realize the focal distance of a lens by shortening. For example, if the focal distance of a lens is set to 0.7mm, the collimated beam diameter will be small made in about about 140 micrometers. For this reason, even if it takes an assembly tolerance into consideration, it is comparatively easy to set the gap of a yoke as the twice [about] as many about 300 micrometers or less as this.

[0094] Drawing 18 is the example of composition of others of the optical variable attenuator of this invention. The magnetic circuit is omitted in order to simplify explanation. In the optical variable attenuator shown in drawing 18 , it converges a light beam in a Faraday cell with the lens by the side of incidence. Therefore, in a Faraday cell, the gap of a yoke can be made still narrower. A light beam can be extracted to about 100 micrometers. If this optical system is applied to an optical variable attenuator, the interval of the gap of a yoke can be narrowed to about 200 micrometers. Therefore, the magnetic field generated in the yoke can be efficiently impressed to a Faraday cell, and drive power can be reduced further.

[0095] Next, the 4th principle of the optical variable attenuator concerning this invention is explained. The wavelength dependency of the gain of optical fiber amplifier can be compensated with the optical variable attenuator concerning this invention by using the wavelength dependency of the magnitude of attenuation. First, the trouble of optical fiber amplifier is explained. As for optical fiber amplifier, Er (erbium) addition optical fiber amplifier (Erbium-DopedFiberAmplifier:EDFA) is used well. This EDFA has the composition which amplifies input light by supplying excitation (pumping) light from the exterior.

[0096] The amplification property of typical EDFA is shown in drawing 19 . The case where, as for drawing 19 , the multiplex multiplexed signal is amplified for four lightwave signals in near 1550nm is shown. EDFA has the peak of gain in nearly 1535nm, and an amplification property is not flat so that I may be understood from this drawing. Therefore, the wavelength-range region near 1540-1560nm where gain is usually comparatively flat is used as a lightwave signal.

[0097] However, also in this wavelength-range region, there is a possibility that a wavelength dependency may increase, by the operating state of optical fiber amplifier. If input control power is increased in the state where fixed control of the output power is carried out, or input control power is fixed and output power is increased as shown in drawing 19 (equivalent to a lower graph in the graph of drawing 19), the gain by the side of near 1540nm short wavelength will fall rather than the 1560nm side.

[0098] In an optical transmission system, since it differs for every place which the length of an optical fiber lays, the power inputted into optical fiber amplifier differs. Therefore, when input control power differs for every construction place, the wavelength dependency of the gain of output power occurs. In order to prevent this wavelength dependency, it is necessary to keep the gain of optical fiber amplifier constant. If gain is controlled uniformly, the rate of the ion of the inverted population state of Er ion in EDFA becomes fixed, and change of a wavelength dependency can be reduced. In this case, the following two problems arise further.

[0099] If gain [in / optical fiber amplifier / always / in the 1st problem] is controlled uniformly, output power will change according to input control power. In this case, in an optical fiber, since light is confined in a very small portion and long-distance propagation of light is performed, the influence of a nonlinear optical effect increases. Therefore, in order to avoid the influence of a nonlinear optical effect, it is necessary to control to reduce the input control power to an optical fiber. For this reason, like drawing 20 , in order to keep an optical output constant, an optical variable attenuator is connected to optical fiber amplifier, and further, in order to reduce change of a wavelength dependency, the gain of optical fiber amplifier is uniformly controlled by the 1st conventional method. In this case, in order to make the wavelength dependency of gain mitigate, it is necessary to make sufficient excitation light power input, and there

are problems, such as increase of power consumption and enlargement of equipment.

[0100] The 2nd problem is enlarging excitation power, when controlling the gain of optical fiber amplifier uniformly and reducing the wavelength dependency of gain. If an inverted population state is set as a predetermined state, gain of the wavelength region of 1540nm - 1560 nm can be mostly made into flatness. However, for that, it is necessary to enlarge excitation power. If excitation power is low, as mentioned above, the inverted population will be in an imperfect state, and the gain by the side of long wavelength will occur. Then, in the 2nd conventional method, the light filter in which the loss by the side of long wavelength has a large property is inserted, and the wavelength dependency of gain can be reduced by few excitation power. However, by this method, a light filter is needed and the composition of equipment becomes complicated.

[0101] Since the above trouble is solved, the optical variable attenuator concerning this invention mentioned above is applicable. Specifically, the optical variable attenuator concerning this invention is applicable as an optical variable attenuator ATT in the composition shown in drawing 20 . In this case, parameters, such as angle arrangement of the polarizer of an optical variable attenuator and an analyzer and FR element length, are adjusted so that it may have a wavelength dependency contrary to the wavelength dependency (wavelength dependency : graph of the drawing 19 bottom when output power is large) of optical fiber amplifier. The damping property of such an optical variable attenuator is shown in drawing 21 . The magnitude of attenuation is increasing to the long wavelength side.

[0102] By applying a **** variable attenuator to transmission equipment, the light filter for canceling a wavelength dependency is removable. Moreover, since the wavelength dependency is large, the wavelength dependency of the gain of optical fiber amplifier is cancellable in a **** variable attenuator, good, so that the magnitude of attenuation is large.

[0103] The latter advantage is further explained to a detail. The latter advantage will be unnecessary if the ideal optical fiber amplifier which is not concerned with input control power but can control gain uniformly exists. However, the excitation light power of actual optical fiber amplifier is limited. When input control power increases, in order to control gain uniformly, it is necessary to raise excitation light power. In order to keep an optical output constant at this time, the magnitude of attenuation of an optical variable attenuator increases.

[0104] However, if input control power increases further and excitation light power reaches a upper limit, it will become impossible to keep an inverted population state constant, and the gain by the side of the long wavelength of optical fiber amplifier will increase. The inclination will become still larger if the upper limit of excitation light power is small. Therefore, if the optical variable attenuator has the property that a wavelength dependency becomes large so that the magnitude of attenuation is large, even if the upper limit of excitation light power is small, the wavelength dependency of gain is effectively cancellable. Therefore, the power of the excitation light of optical fiber amplifier can be set up small, and the miniaturization of optical fiber amplifier and low-power-ization are attained.

[0105] in addition, in the optical variable attenuator which has such a big wavelength dependency, the temperature dependence of the magnitude of attenuation is also large -- it is expected Therefore, it is desirable to add the control circuit which keeps the temperature of a Faraday cell constant in this case. Next, the 5th principle of the optical variable attenuator concerning this invention is explained. In case it controls by the optical variable attenuator using the magneto-optical effect to the same magnitude of attenuation, the drive current impressed to an electromagnet may differ by the case of the control to which the magnitude of attenuation is made to increase, and the case of the control which decreases the magnitude of attenuation. This originates in angle of rotation of a Faraday cell, or the hysteresis characteristic of a magnetic circuit.

[0106] Drawing 22 is an example of composition for explaining the 5th principle of the optical variable attenuator concerning this invention. The input-control-power change to an optical variable attenuator is oppressed, and it can control by this composition to keep output power constant. In the example of composition shown in drawing 22 , the optical variable attenuator shown in drawing 30 is used. In this optical variable attenuator, as a polarizer and an analyzer, in order to reduce the polarization dependency of the magnitude of attenuation, what processed the optical material which has birefringences, such as a rutile (rutil : titanium dioxide TiO_2) and a calcite, in the shape of a wedge is used. When decreasing a space beam, without preparing a fiber in I/O, or when using a polarization maintenance fiber as an I/O fiber, the linearly polarized light is inputted into an optical variable attenuator. In this case, the polarization eliminator which used usual prism and a usual dielectric multilayer as a polarizer and an analyzer can be used. Moreover, in drawing 22 , in order to simplify explanation, the permanent magnet which gives a bias magnetic field is omitted.

[0107] The aperture 104 which lets one side of two light beams which carried out the birefringence of a part of two light beams which carried out the birefringence to the output side of an optical variable attenuator to the branched optical coupler 100 and the lens 102 pass, and the electric eye 106 which carries out the monitor of the optical power which passed aperture 104 are formed, and the magnitude of attenuation of an optical variable attenuator is controlled

by the optical variable attenuator of drawing 22 so that optical power becomes a predetermined value. The light beam which passed analyzer 8b (birefringence crystal) of an output side separates a part of light beam with the optical coupler 100. The separated light beam is inputted into an electric eye 106 through a lens 102 and aperture 104.

[0108] The branching ratio of the optical coupler 100 has the slight magnitude of attenuation of the main signal supplied to fiber 6b, and it is set up so that the monitor of the branched light beam can be enough carried out in an electric eye 106. For example, a branching ratio can be set about to 10:1 to 20:1. In the optical variable attenuator of drawing 22 , the light beam separated with the optical coupler is inputted into an electric eye 106 through a lens 102 and aperture 104. In the optical variable attenuator which used the birefringence tapered sheet as a polarizer and an analyzer, the polarization direction of a light beam rotates in the Faraday-rotation child 9, and a gap arises in the joint position in output optical fiber 6b of a light beam. Therefore, a part of light beam is not supplied to optical fiber 6b, but attenuation operation is performed.

[0109] When the magnitude of attenuation is zero, a light beam is combined in the center of the core of output fiber 6b. Since attenuation is produced, if Faraday rotation is given in the polarization direction of a light beam, from a core, a light beam will combine with the position shifted and optical power will decline. Therefore, if light-receiving area is not extracted small enough like an optical fiber when receiving the separated light beam by the electric eye 106, light beams are supplied [no] to an electric eye 106, and can measure power of a light beam correctly. That is, if the diameter of light-receiving is larger than the position gap even if it changes the position to combine, the magnitude of attenuation cannot be measured. In addition, if the focal distance of the lens by the side of a monitor etc. is set up suitably, the light-receiving side of a bigger area than the core of an optical fiber is securable. Therefore, aperture 104 is formed in the front face of an electric eye 106. Aperture is unnecessary when a light-receiving side is sufficiently small.

[0110] Next, operation of the control circuit prepared in the exterior of the optical variable attenuator of drawing 22 is explained. The electrical signal which carried out photo electric translation by the electric eye 106 is amplified by the electrical signal of suitable level with amplifier 108. The amplified electrical signal is inputted into the error detector 110. The control-voltage generating circuit 112 outputs the voltage corresponding to desired optical power. The relation between the impression power to the coil of an optical variable attenuator and the magnitude of attenuation is prepared in the linear riser 114 at the amendment sake. Although a Faraday-rotation angle is proportional to impression power, the magnitude of attenuation is cos2 of a Faraday-rotation angle. It is proportional. Therefore, a programmed voltage is amended so that it may become the relation between alignment or a logarithm about the relation between a programmed voltage and output light power. This programmed voltage is inputted into the error detector 110 with the above-mentioned electrical signal, and is outputted as an error signal which the signal of those difference should control.

[0111] Adjustment of the time constant of an electrical circuit is performed by the phase compensation circuit 116 in the error signal outputted from the error detector 110. Since the coil of the electromagnet which produces Faraday rotation has the inductance, it has a possibility of a response characteristic deteriorating and generating a ringing. Therefore, in the phase compensation circuit 116, in order to prevent them, the frequency characteristic of a control circuit is adjusted. The drive circuit 118 is a power amplification circuit for driving a coil.

[0112] By using the control mentioned above, the output power equivalent to the programmed voltage generated in the control-voltage generating circuit 112 can always be obtained. In addition, the remote control of the control-voltage generating circuit 112 is attained by giving the control voltage from the outside. In this example of composition, amendment of the temperature characteristic of an optical variable attenuator, degradation with the passage of time, polarization loss change, etc. is also attained.

[0113] Drawing 23 is an example of change of an optical variable attenuator shown in drawing 22 . In the **** variable attenuator, the branching means and light-receiving means of a light beam are further added to the input side of an optical variable attenuator compared with the optical variable attenuator shown in drawing 22 . It is controllable by this example of composition to obtain the predetermined magnitude of attenuation regardless of input light power. The same reference number is given to the element which has the same function as drawing 22 .

[0114] In the **** variable attenuator, optical coupler 100a and electric-eye 106a are prepared in the input side like the output side. A part of input light power (for example, 1 / 10 - 1/20) branches, and a monitor is carried out by electric-eye 106a. Since a part of optical power has branched before an input side passes the polarizer which consists of a birefringence tapered sheet, the aperture 104 for restricting the diameter of light-receiving prepared in the output side is unnecessary.

[0115] In the optical variable attenuator of drawing 23 , the signal which received light by the electric eyes 106a and 106b of an input side and an output side is amplified to suitable level with Amplifier 108a and 108b, and is inputted into a ratio circuit 120. In this ratio circuit 120, the ratio of output power and input control power is calculated. This

result of an operation is inputted into the error detector 110. Simultaneously with it, the programmed voltage corresponding to the magnitude of attenuation is also inputted into the error detector 110. The error detector 110 generates a control error signal, and phase compensation of the signal is carried out, and it drives a coil through the drive circuit 118. It is controlled by the above-mentioned control circuit so that the ratio of the optical power of the input section and the output section becomes fixed, and the magnitude of attenuation of an optical variable attenuator can control by it uniformly.

[0116] Next, the 6th principle of the optical variable attenuator concerning this invention is explained. When it mounts an optical variable attenuator in an optical transmission device, it is necessary to miniaturize an optical variable attenuator. Since it may mount on the printed circuit board and transmission equipment may be especially constituted for the printed circuit board in piles, it is necessary to make the height of an optical variable attenuator low. Furthermore, it is important to reduce the power consumption of an optical variable attenuator for reduction of the power consumption of an optical transmission device.

[0117] Drawing 24 is an example of composition for explaining the 6th principle of the optical variable attenuator concerning this invention. Drawing which looked at (A) to the external view and looked at (B) in the direction of a, and (C) are drawings seen in the direction of b. However, in drawing 24 , in order to simplify explanation, only the Faraday-rotation child has indicated and the polarizer and the analyzer are omitted.

[0118] The Faraday-rotation child who shows drawing 24 consists of Faraday cell 130, an electromagnet 132 which has a yoke 134 and a coil 136, and a permanent magnet 138. The yoke 134 and permanent magnet 138 of an electromagnet 132 have constituted the ring configuration (for example, horseshoe shape) which has a gap. Faraday cell 130 is formed in the gap of a yoke 134. An electromagnet 132 impresses a magnetic field in the direction perpendicular to a light beam 140, and the permanent magnet 138 is impressing the magnetic field to Faraday cell 130 in the direction of a light beam 140 at Faraday cell 130.

[0119] Especially (C) of drawing 24 shows signs that the optical variable attenuator is contained by the case 142. In this drawing, the direction of the gap of an electromagnet 132 is arranged in the height direction of a case 142. therefore, the light beam 140 -- the height of a case 142 -- it can be mostly located in the middle

[0120] As mentioned above, it is desirable for the height of an optical device to be low by the reasons of mounting. Since the yoke of an electromagnet has a ring-like form in the case of the optical variable attenuator, this diameter influences the height of an optical variable attenuator greatly. Specifically, it is desirable on an interface with the exterior to set up the position of a light beam in the middle of the height of an optical variable attenuator. In the conventional optical variable attenuator shown in drawing 29 , the space which is equivalent to the diameter of a ring-like yoke, respectively is required for light beam a top and the bottom, and the height of an optical variable attenuator becomes large. However, what is necessary is just to secure the space which is equivalent to the radius of a ring-like yoke, respectively to light beam 140 a top and the bottom in the example of composition of an optical variable attenuator shown in drawing 24 . Therefore, the height of an optical variable attenuator can be made low.

[0121] At (B) of drawing 24 , a permanent magnet 138 has a horseshoe-shaped configuration, and in the range which does not interrupt a light beam 140, proximity installation is carried out so that it may be inserted into Faraday cell 130. Moreover, it is shown that the point of the yoke of a permanent magnet 138 is thin. By the above-mentioned composition, the magnetic field of a permanent magnet 138 can be efficiently impressed to Faraday cell 130 compared with the conventional optical variable attenuator shown in drawing 29 . Therefore, a permanent magnet 138 can prevent revealing a magnetic field outside, and the influence on an electromagnet can also reduce it. Thereby, it can prevent control of an electromagnet becoming complicated. Furthermore, the magnetism of a permanent magnet 138 can be reduced in this case.

[0122] Furthermore, as shown in (A) of drawing 24 , the yoke 134 of an electromagnet 132 contains the half-hard magnetic substance 144 in the portion near a gap. In the conventional optical variable attenuator shown in drawing 29 , since all yokes are formed with the elasticity magnetic substance, in order to supply a magnetic field, it is always necessary to supply current to an electromagnet. If the half-hard magnetic substance is used for the yoke of an electromagnet as shown in drawing 24 , a yoke is magnetized by impression of a pulse current, and the magnetization will be held even if it stops supply of current. Therefore, the power consumption of an optical variable attenuator can be reduced. In this case, it is not necessary to constitute the whole yoke from the half-hard magnetic substance, and the effect is acquired also by preparing the half-hard magnetic substance partially into a yoke, as shown in drawing 24 (A).

[0123] However, the half-hard magnetic substance is difficult for a big hysteresis characteristic being shown and obtaining stable magnetization in an unsaturation field, although the stable magnetization is obtained in a saturation region. Therefore, control on the intermediate-stage story of a magnetic field is difficult. In order to solve this problem, the composition shown in drawing 25 can be considered. Drawing 25 is drawing showing the composition of the

electromagnet used for the optical variable attenuator concerning this invention.

[0124] With this electromagnet, two or more half-hard magnetic substance 144a-144e with which the magnetism in each saturation region differs partially is formed into the yoke of an electromagnet. Moreover, in each half-hard magnetic substance, the coil is prepared individually, and each ****** magnetic substance can be driven by the saturation region in independent to it. Therefore, by carrying out ON/OFF control of the current supplied to these coils, only the desired half-hard magnetic substance can be operated and the magnetic field gradually generated with an electromagnet can be set up stably.

[0125] Next, the 7th principle of the optical variable attenuator concerning this invention is explained. In the optical variable attenuator using the wedge-like birefringence crystal, as the conventional optical variable attenuator of drawing 30 explained, slight polarization dependency loss (PDL) occurs. The optical variable attenuator concerning this invention reduces this polarization dependency loss further.

[0126] Drawing 26 is an example of composition for explaining the 7th principle of the optical variable attenuator concerning this invention. (A) is a plan and (B) is a side elevation. Drawing 27 is drawing showing the direction pattern of the bias magnetic field for explaining the 7th principle of the optical variable attenuator concerning this invention. (A) is the case where (B) impresses a bias magnetic field to a refraction flat surface and parallel, when impressing a bias magnetic field at right angles to a refraction flat surface.

[0127] The bias magnetic field 154 for the optical variable attenuator shown in drawing 26 simplifying the magnetic domain of Faraday cell 150 compared with the optical variable attenuator shown in drawing 30 is shown. This bias magnetic field 154 is perpendicularly impressed to Faraday cell 150 to a light beam. The magnet 152 for generating the bias magnetic field 154 is shown in (B) of drawing 26 , and is omitted by (A). Moreover, in fact, in order to generate Faraday rotation, a magnetic field parallel to a light beam is also impressed to Faraday cell 150. However, in these drawings, in order to simplify explanation, illustration of a magnetic field parallel to a light beam is omitted. Other composition is the same as the optical variable attenuator shown in drawing 30 , and gives the same reference number to the element which has the same function.

[0128] In the optical variable attenuator of drawing 26 , the birefringence of the light beam is carried out in birefringence crystal 8a, and it is changed into the light beam which has the component of Tsunemitsu from whom the degree of angle of refraction differs, and unusual light. In Faraday cell 150, the bias magnetic field 154 is supplied to Tsunemitsu and unusual light. This bias magnetic field 154 is perpendicularly impressed to the flat surface (a refraction flat surface is called) which consists of Tsunemitsu 156 and unusual light 158. This situation is shown in (A) of drawing 27 . Therefore, the bias magnetic field 154 of the size with same Tsunemitsu 156 and unusual light 158 is impressed.

[0129] On the other hand, as shown in (B) of drawing 27 , a bias magnetic field can also be impressed in parallel to a refraction flat surface. However, a bias magnetic field is substantially impressed perpendicularly to a light beam. In this case, since Tsunemitsu 156 and the unusual light 158 have different angle of refraction, the bias magnetic fields impressed to each light differ slightly. It is considered by the difference of the size of this magnetic field for polarization dependency loss to occur.

[0130] Therefore, as shown in drawing 26 or drawing 27 (A), polarization dependency loss can be reduced by impressing a bias magnetic field to a refraction flat surface perpendicularly substantially. In the optical variable attenuator concerning this invention mentioned above in this specification, since control of the magnitude of attenuation is performed using two kinds of magnetic circuits, a possibility that the magnetic field of a magnetic circuit may be revealed is in the exterior of an optical variable attenuator. Especially the magnetic field of a permanent magnet is strong, and its influence on the exterior is large. In order to make this influence mitigate, the method of preparing a yoke in a permanent magnet as well as an electromagnet, or carrying out magnetic shielding of the case to it is effective.

[0131] As mentioned above, although the example of this invention explained, this invention is not limited to these examples and it cannot be overemphasized that improvement and deformation are possible within the limits of this invention.

[0132]

[Effect of the Invention] As mentioned above, according to this invention, it has the effect taken below. In the optical variable attenuator given in any 1 term, the polarization direction of the aforementioned analyzer is substantially set as the rectangular state with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal a claim 1 or among 3.

[0133] In this case, when a Faraday-rotation angle is large, the variation of a Faraday-rotation angle to change of wavelength is also large. However, since the variation of the magnitude of attenuation to change of a Faraday-rotation angle is small, the variation of the magnitude of attenuation to change of wavelength can be reduced. Moreover, when

a Faraday-rotation angle is small, the variation of a Faraday-rotation angle to change of wavelength is also small. Therefore, in this case, although the variation of the receiving magnitude of attenuation to change of a Faraday-rotation angle is large, the variation of the magnitude of attenuation to change of wavelength can be reduced.

[0134] Therefore, the wavelength dependency of the magnitude of attenuation can be reduced in a **** variable attenuator. Moreover, the temperature dependence of the magnitude of attenuation can be reduced similarly. In the optical variable attenuator given in any 1 term, the magnetic field generated with the permanent magnet or its part is always impressed to a light beam and parallel at the magneto optics crystal a claim 4 or among 6. Therefore, in a **** variable attenuator, even if the current impressed to a magnetic circuit will not flow by failure etc., a light beam can be penetrated. Consequently, the influence which it has on operation of transmission equipment can be reduced. Furthermore, wavelength and temperature dependence can also be reduced.

[0135] Especially, at an optical variable attenuator according to claim 5, an above-mentioned effect can be acquired with simpler composition. In an optical variable attenuator given in any 1 term, a magneto optics crystal (Faraday cell) can be inserted without a crevice into the gap of a yoke a claim 7 or among 10. Therefore, the magnetic field generated in the yoke can be efficiently supplied to a magneto optics crystal, without leaking outside, consequently can impress uniformly a magnetic field strong against a magneto optics crystal. Therefore, the current supplied at a magnetic circuit compared with composition with a crevice between a magneto optics crystal and a yoke can be reduced, and the drive power of a magnetic circuit can be reduced.

[0136] Especially, in an optical variable attenuator according to claim 8, by preparing the coil near the magneto optics crystal, the influence of the magnetic reluctance in a yoke is reduced, and the magnetic field efficiently generated in the yoke can be supplied to a magneto optics crystal. Therefore, the drive power of an electromagnet can be reduced more. Furthermore, since the height by the side of the loop of a yoke can be made low, the height of an optical variable attenuator can also be made low, consequently the ease of mounting improves.

[0137] Moreover, in an optical variable attenuator according to claim 9 or 10, the interval of the gap of a yoke can be narrowed to about 200 micrometers. Therefore, the magnetic field generated in the yoke can be efficiently impressed to a Faraday cell, and drive power can be reduced further.

[0138] In light amplifier according to claim 11 or 12 and an optical variable attenuator according to claim 13, the wavelength dependency of the magnitude of attenuation can be arbitrarily set up by adjusting the polarization direction of an analyzer, the polarization direction of a lightwave signal, and a magneto optics crystal. Therefore, the wavelength dependency of the gain of a light amplifier can be reduced without using the light filter for gain equalization. Moreover, in a **** variable attenuator, a wavelength dependency is greatly made, so that the magnitude of attenuation is large. Therefore, the wavelength dependency of the gain of a light amplifier when the upper limit of optical-pumping power is small is cancellable good. Therefore, the power of the excitation light of optical fiber amplifier can be set up small, and the miniaturization of optical fiber amplifier and low-power-ization are attained.

[0139] A claim 14 or among 16, it is controlled, or it is controlled so that a ratio with the output power of the optical variable attenuator which carried out the monitor by the power and the output side electric eye of the light beam which carried out the monitor by the input-side electric eye becomes a predetermined value so that the output-power power of the optical variable attenuator which carried out the monitor by the output side electric eye in the optical variable attenuator given in any 1 term becomes a predetermined value. Therefore, amendment of the temperature characteristic of the magnitude of attenuation of an optical variable attenuator, degradation with the passage of time, polarization loss change, etc. is attained.

[0140] What is necessary is just to secure the space which is equivalent to the radius of a ring-like yoke, respectively to light beam a top and the bottom in an optical variable attenuator according to claim 17, if a magnetic circuit is constituted from a ring-like yoke. Therefore, the height of an optical variable attenuator can be made low.

[0141] In an optical variable attenuator according to claim 18 or 19, the magnetic field of a magnetic circuit can be efficiently impressed to a magneto optics crystal. Therefore, a magnetic circuit can prevent revealing a magnetic field outside, and can also reduce the influence of the magnet on others. In an optical variable attenuator according to claim 20, a yoke contains the half-hard magnetic substance in part at least. Therefore, a yoke is magnetized by impression of a pulse current, and the magnetization is held even if it stops supply of current. Therefore, the power consumption of an optical variable attenuator can be reduced.

[0142] In an optical variable attenuator according to claim 21, the magnetic field generated with an electromagnet can be stably set up gradually by controlling two or more half-hard magnetic substance with which magnetization differs. In an optical variable attenuator according to claim 22, the bias magnetic field for simplifying the magnetic domain of a magneto optics crystal is substantially impressed perpendicularly by the refraction flat surface. Thereby, polarization dependency loss can be reduced.

[Translation done.]

* NOTICES *

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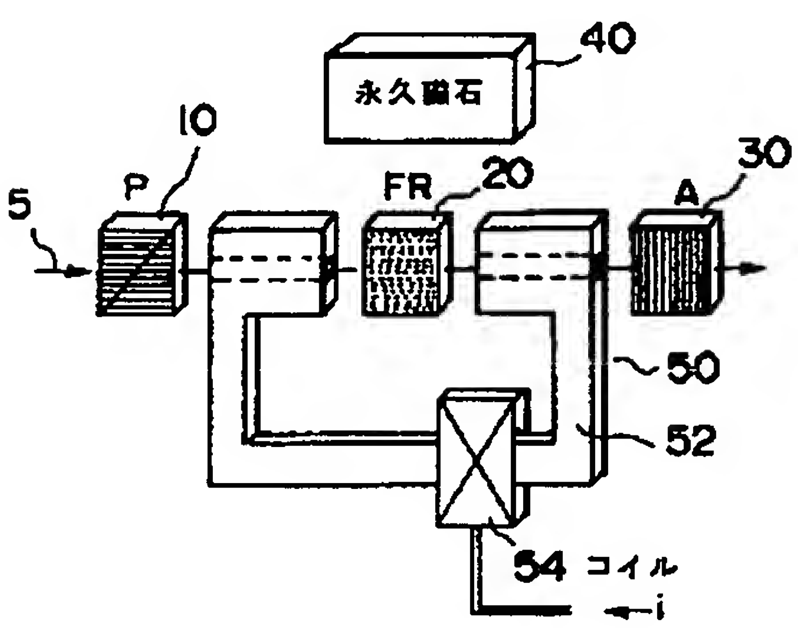
1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

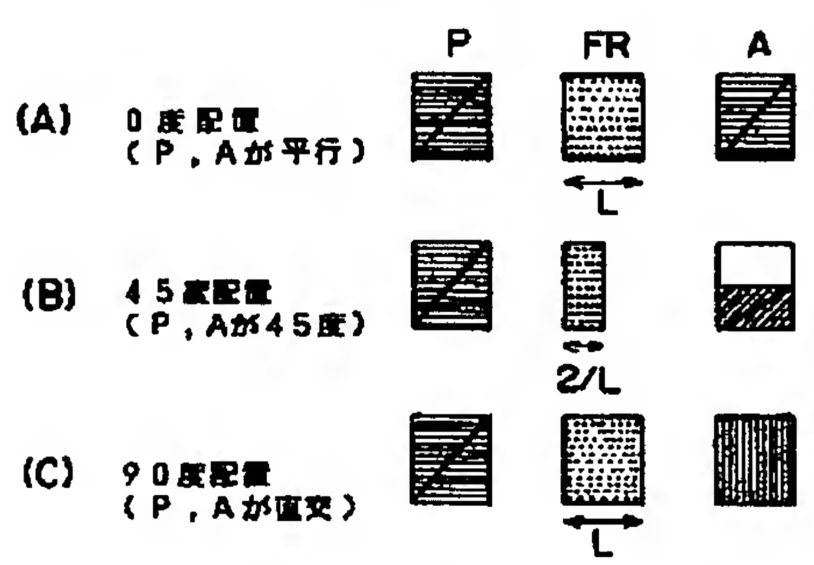
DRAWINGS

[Drawing 1]
本発明に係わる光可変減衰器の構成例

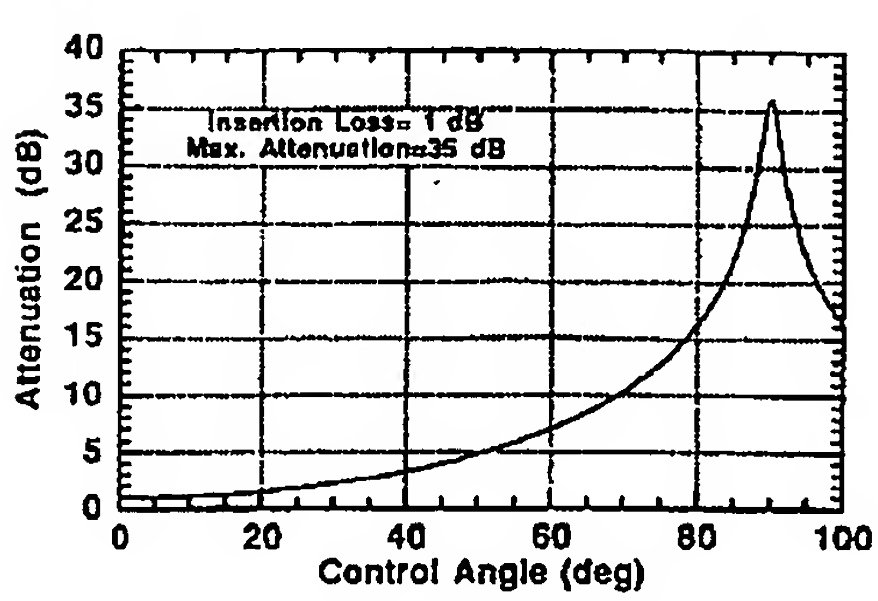


[Drawing 2]

偏光子（P）、ファラデー素子（ＦＲ）、検光子（A）の配置例。（A）は、０度配置と称し、偏光子の偏光方向と検光子の偏光方向が平行である場合、（B）は、４５度配置と称し、偏光子の偏光方向と検光子の偏光方向との角度差が４５度の場合、（C）は、９０度配置と称し、偏光子の偏光方向と検光子の偏光方向が直交している場合

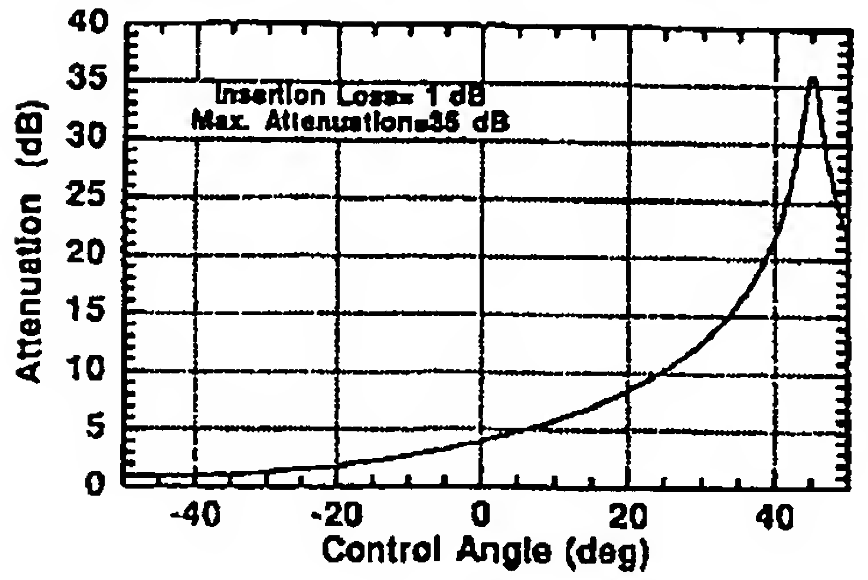


[Drawing 3]
０度配置の場合のファラデー回転角に対する減衰量の計算結果



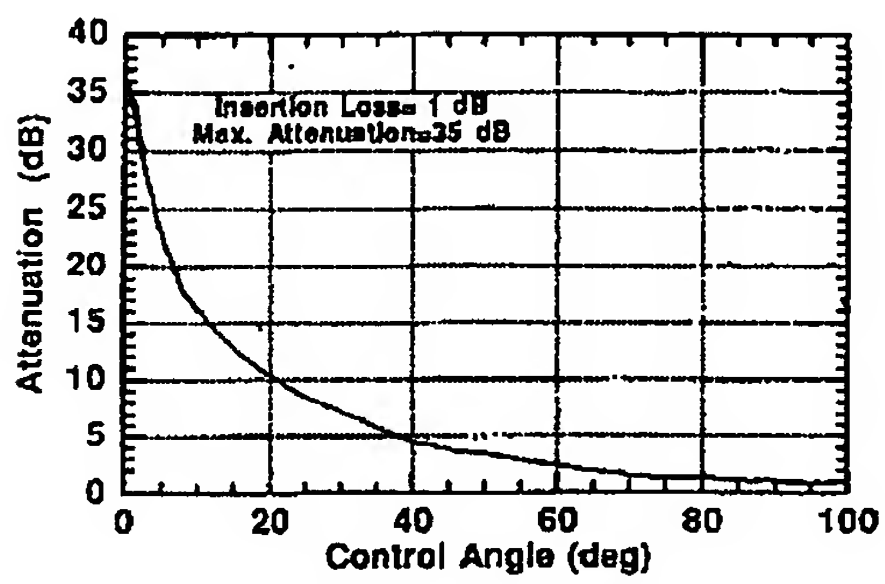
[Drawing 4]

４５度配置の場合のファラデー回転角に対する減衰量の計算結果



[Drawing 5]

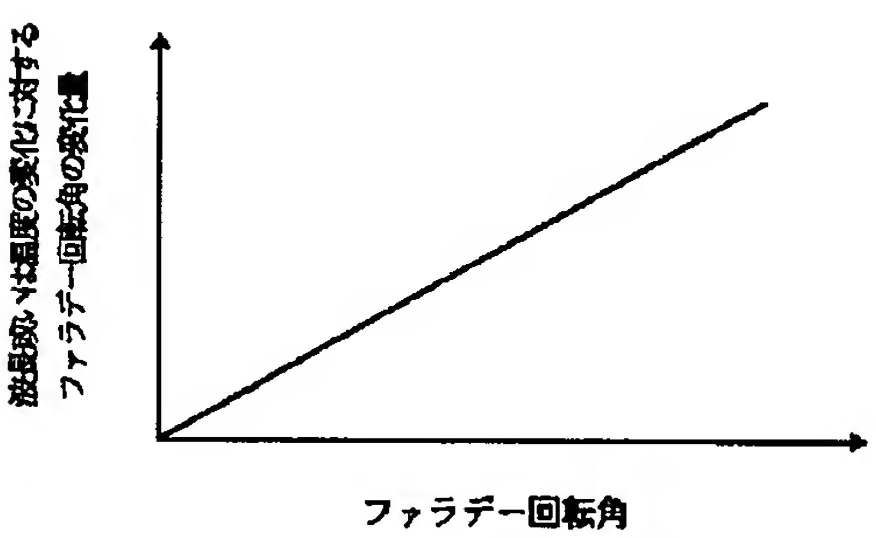
９０度配置の場合のファラデー回転角に対する減衰量の計算結果



[Drawing 6]

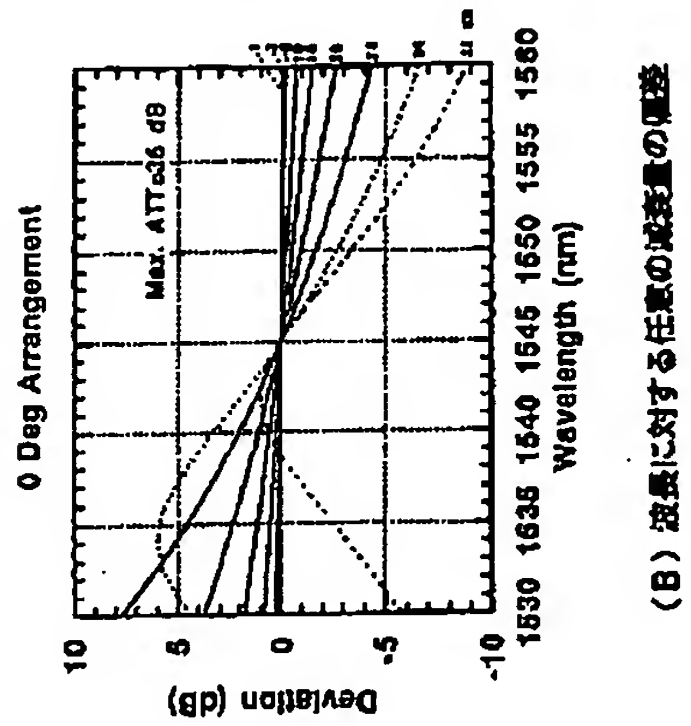
ファラデー回転角と波長或いは温度の変化に対する

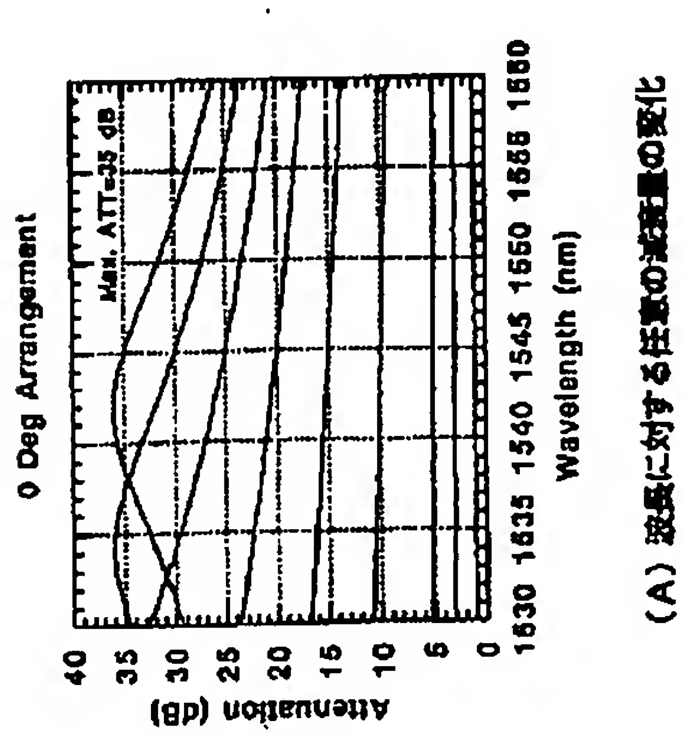
ファラデー回転角の変化量との模式的な関係図



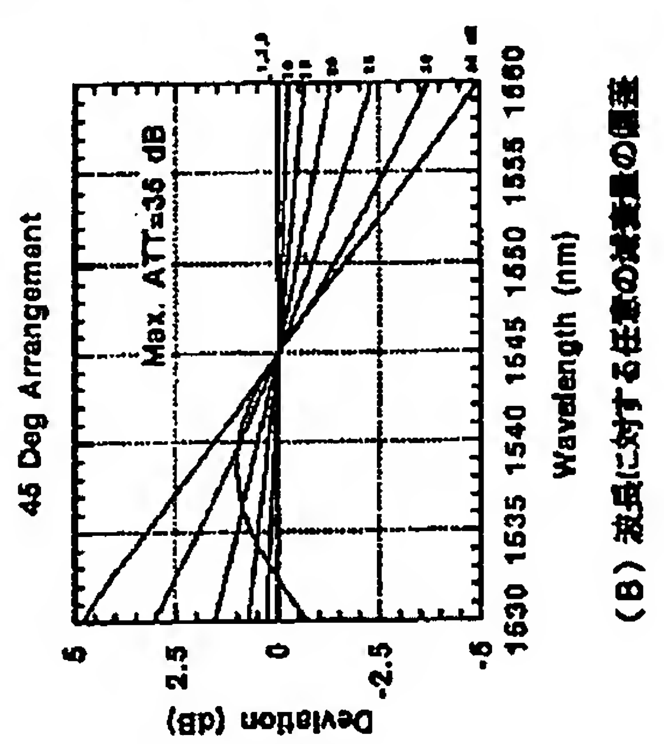
[Drawing 7]

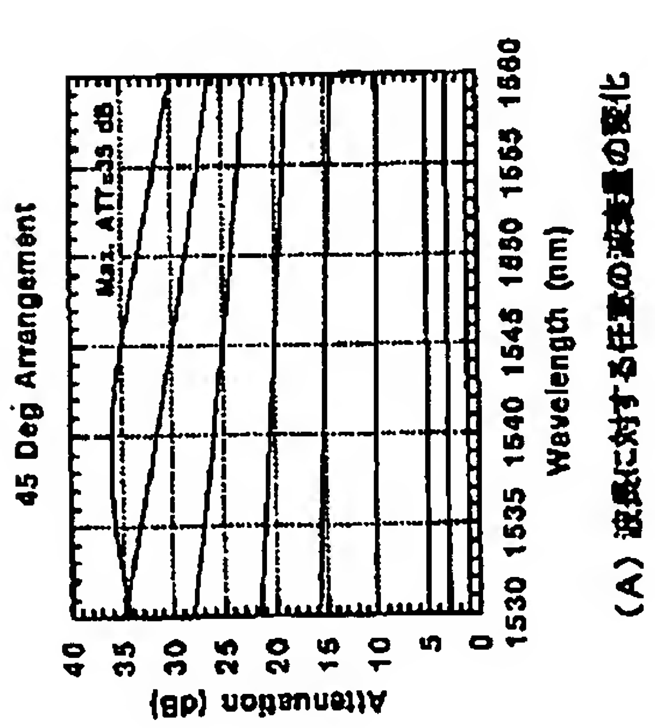
偏光子と検光子の偏光方向の角度差が０度の場合の
波長に対する減衰特性



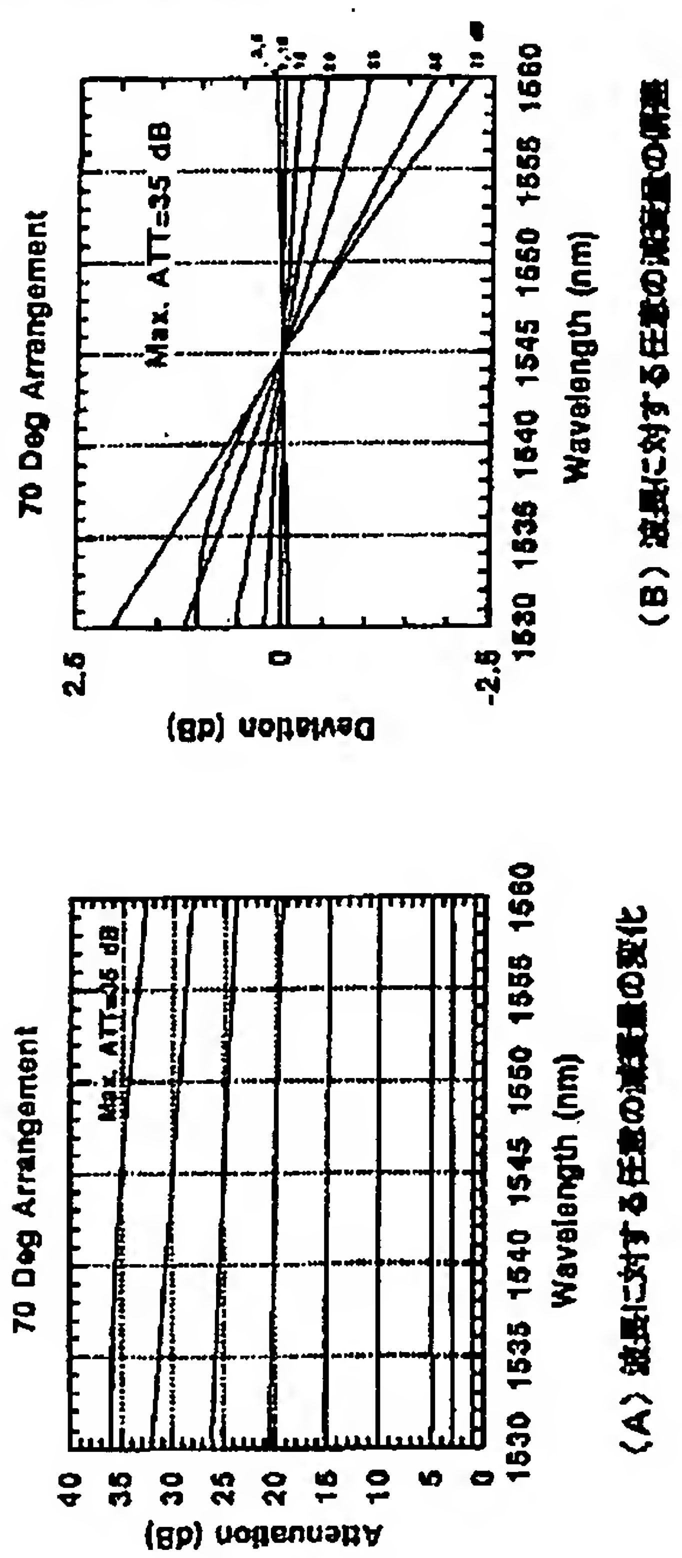


[Drawing 8]
偏光子と検光子の偏光方向の角度差が４５度の場合の
波長に対する減衰特性

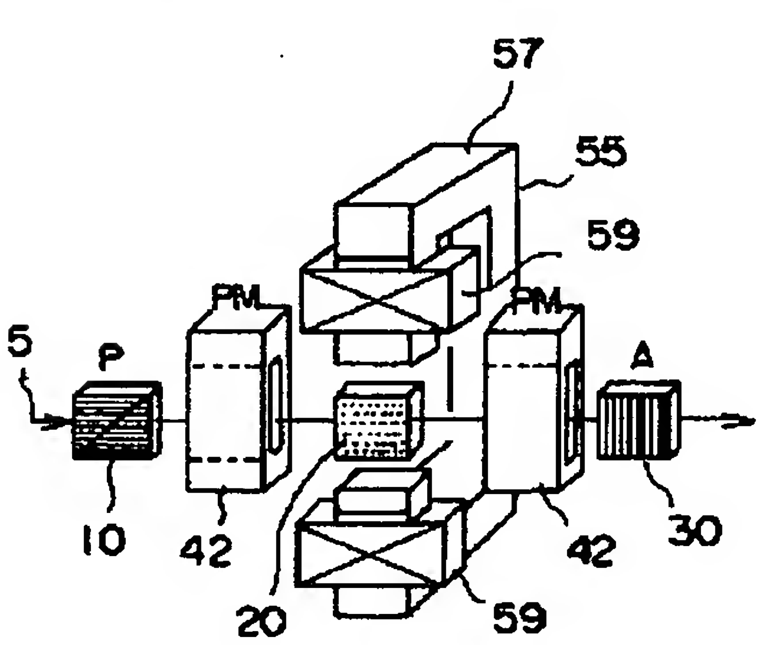




[Drawing 9]
偏光子と検光子の偏光方向の角度差が７０度の場合の
波長に対する減衰特性

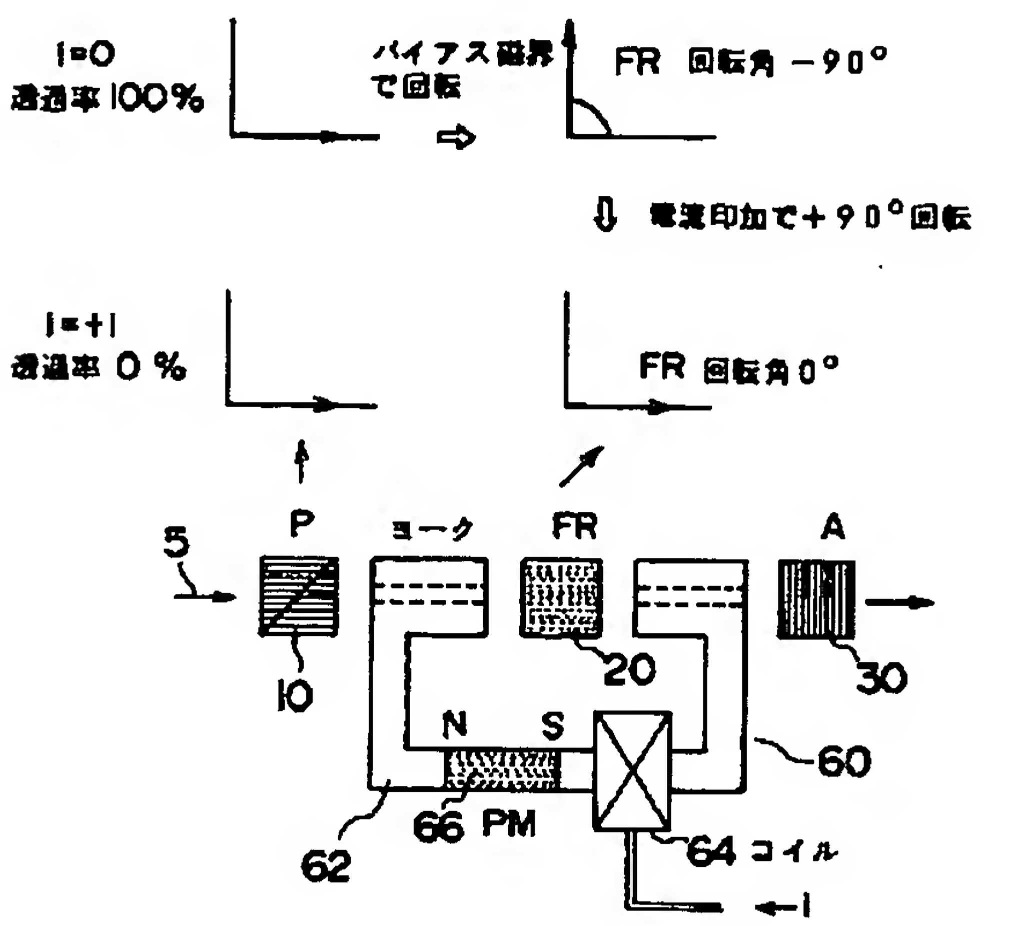


[Drawing 12]
本発明に係わる光可変減衰器の他の構成例



[Drawing 13]

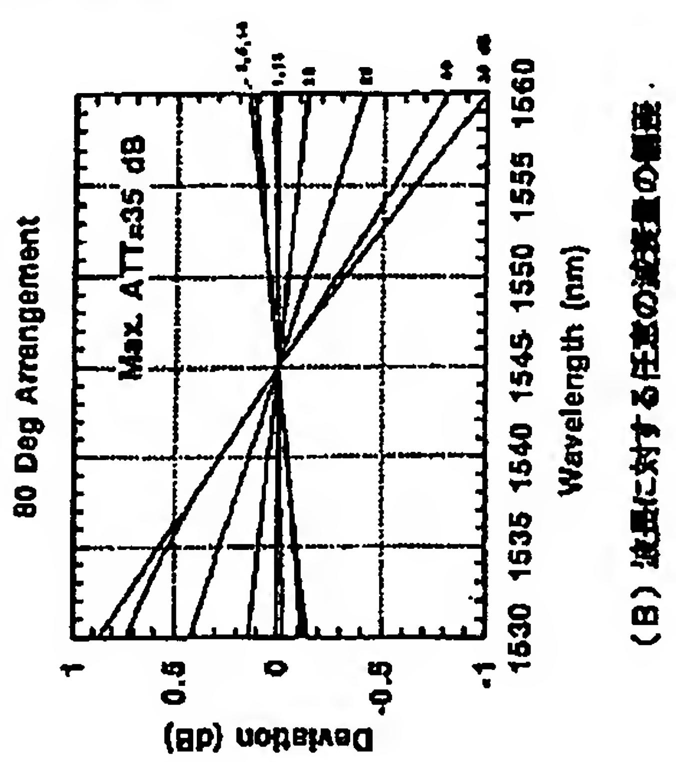
本発明に係わる光可変減衰器の第２の原理を説明するための図

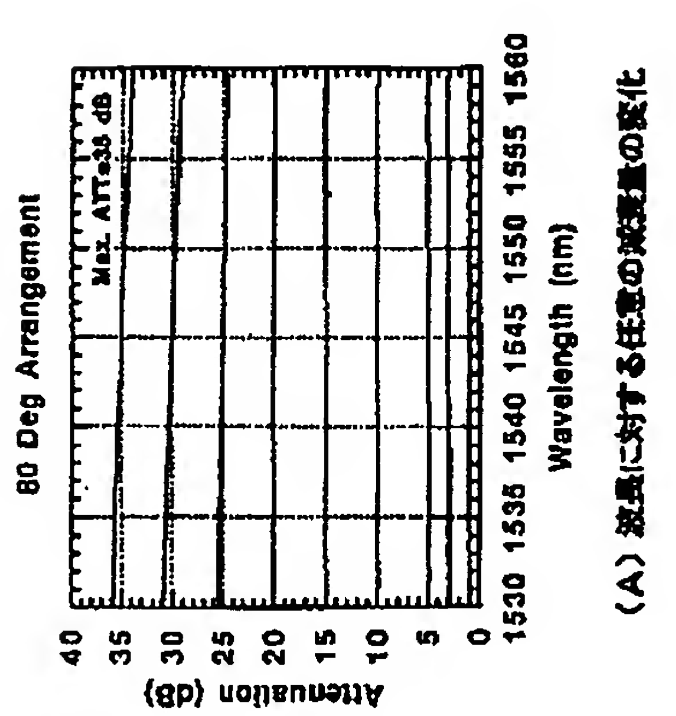


[Drawing 10]

偏光子と検光子の偏光方向の角度差が８０度の場合の

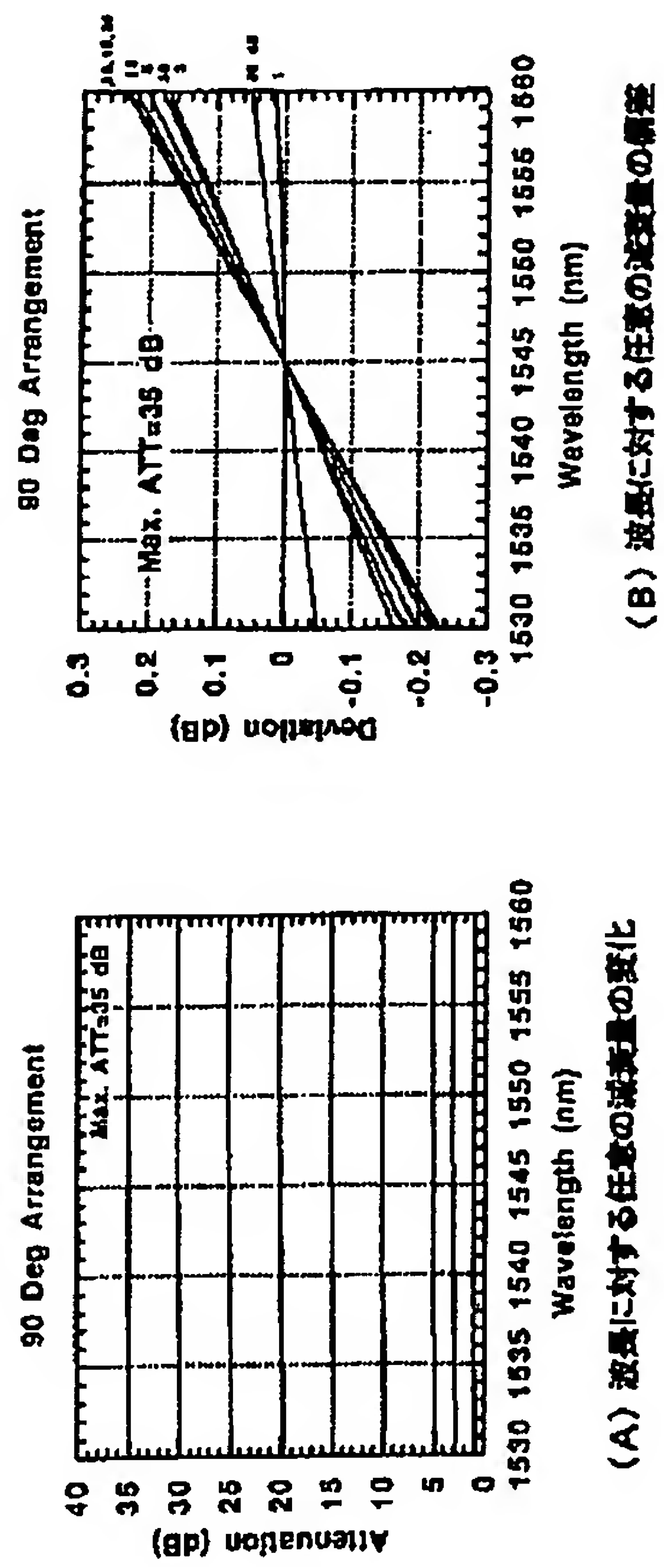
波長に対する減衰特性





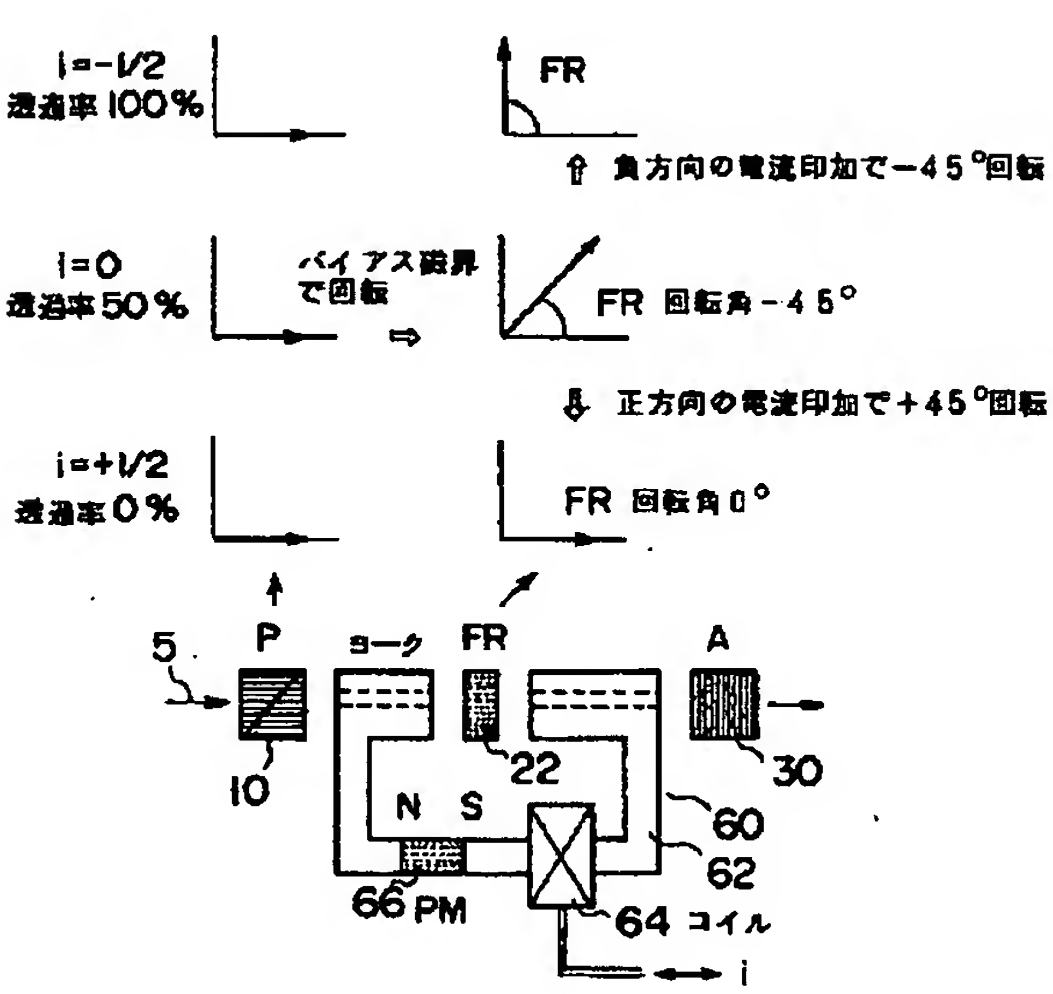
[Drawing 11]

偏光子と検光子の偏光方向の角度差が90度の場合の
波長に対する減衰特性



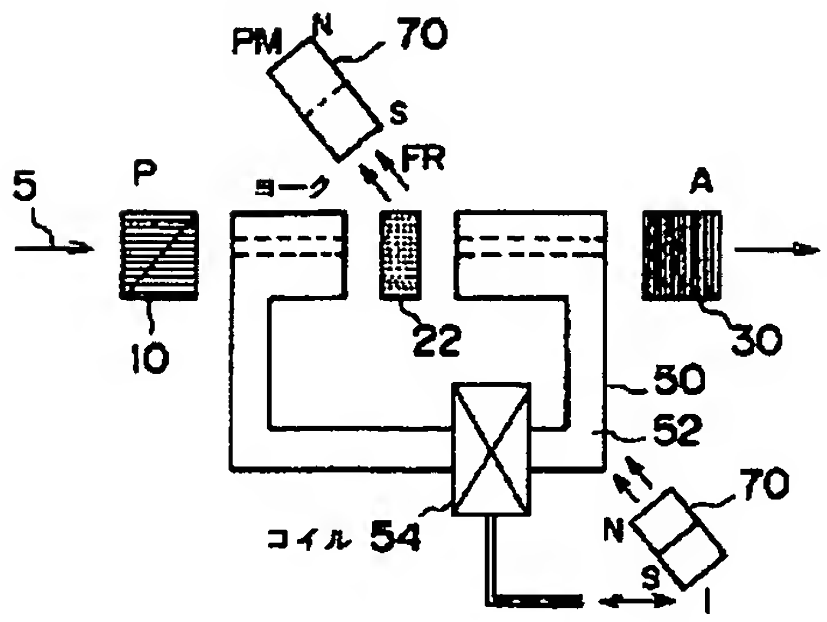
[Drawing 14]

図13に示す光可変減衰器の変更例



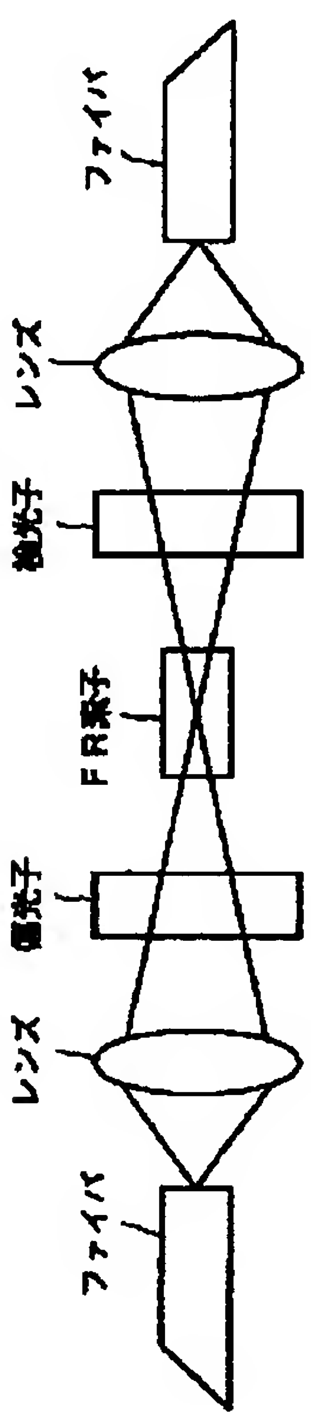
[Drawing 15]

図１４に示す光可変減衰器の変更例



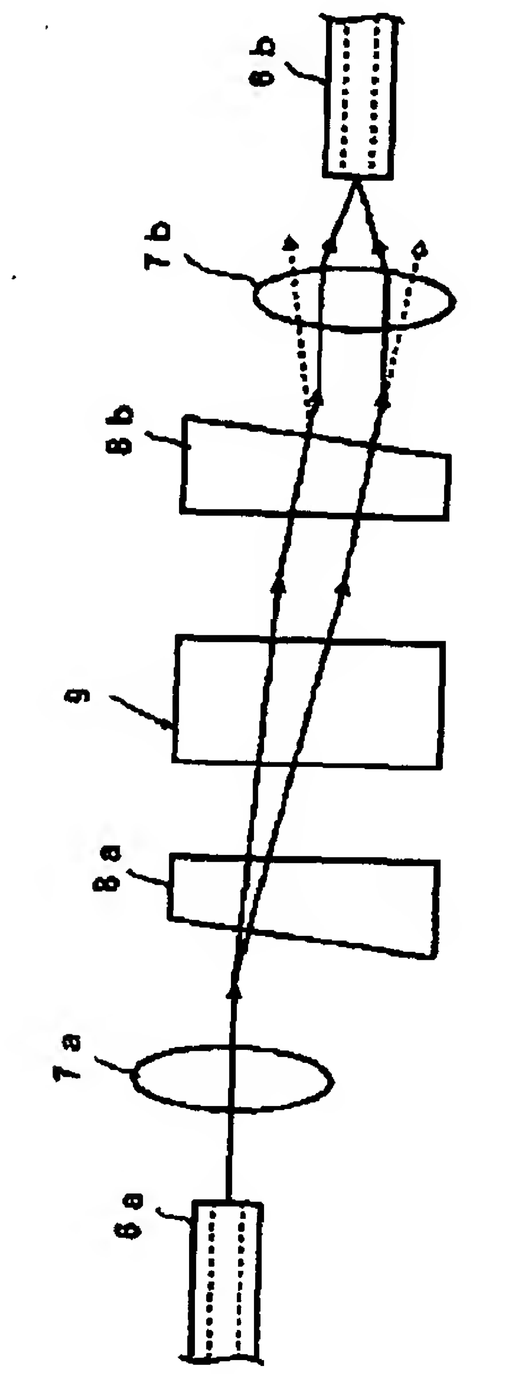
[Drawing 18]

本発明の光可変減衰器のその他の構成例



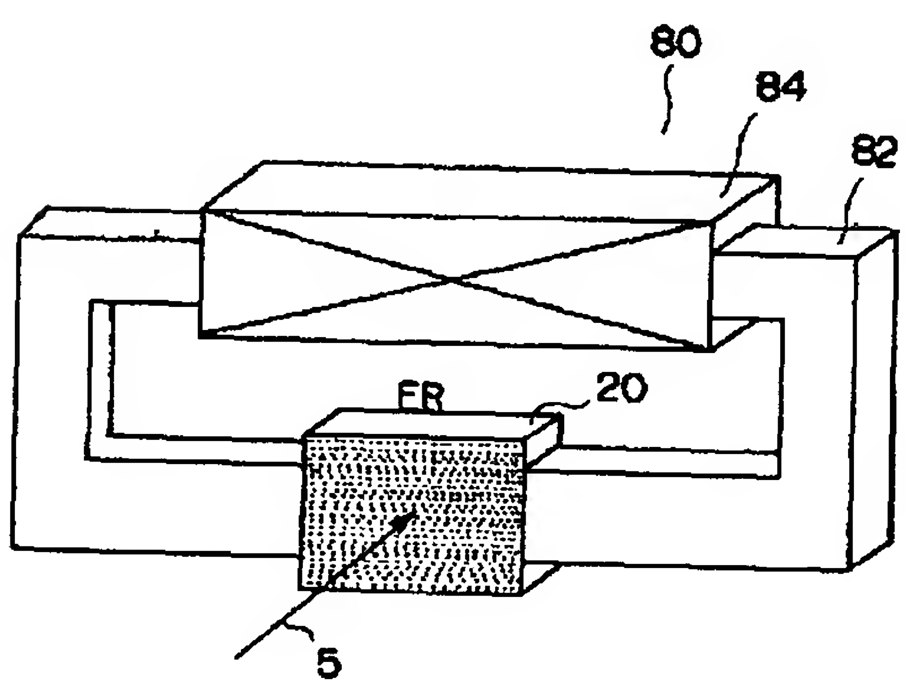
[Drawing 30]

従来の光可変減衰器の第2の構成例



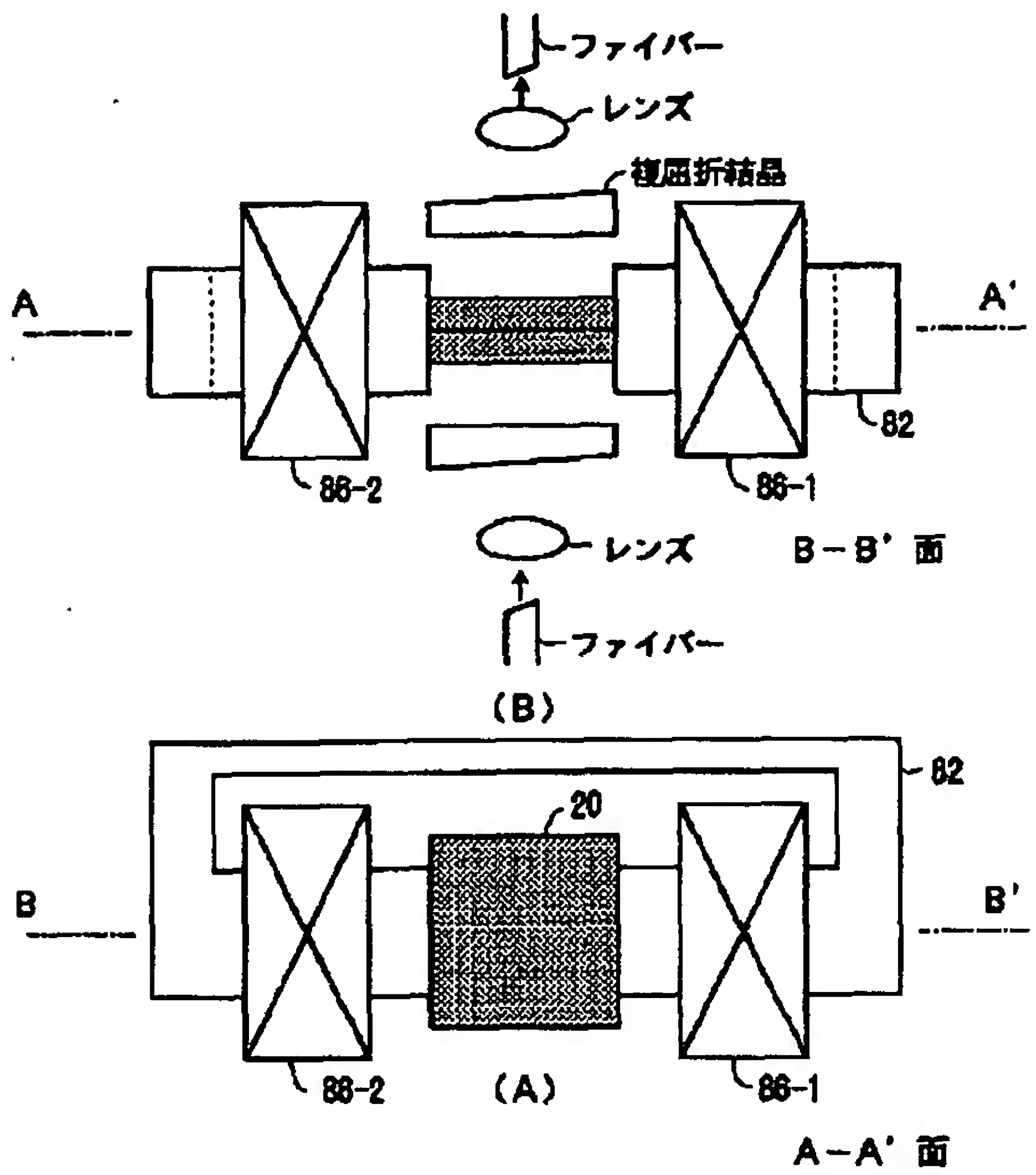
[Drawing 16]

本発明に係わる光可変減衰器の磁気回路の構成例

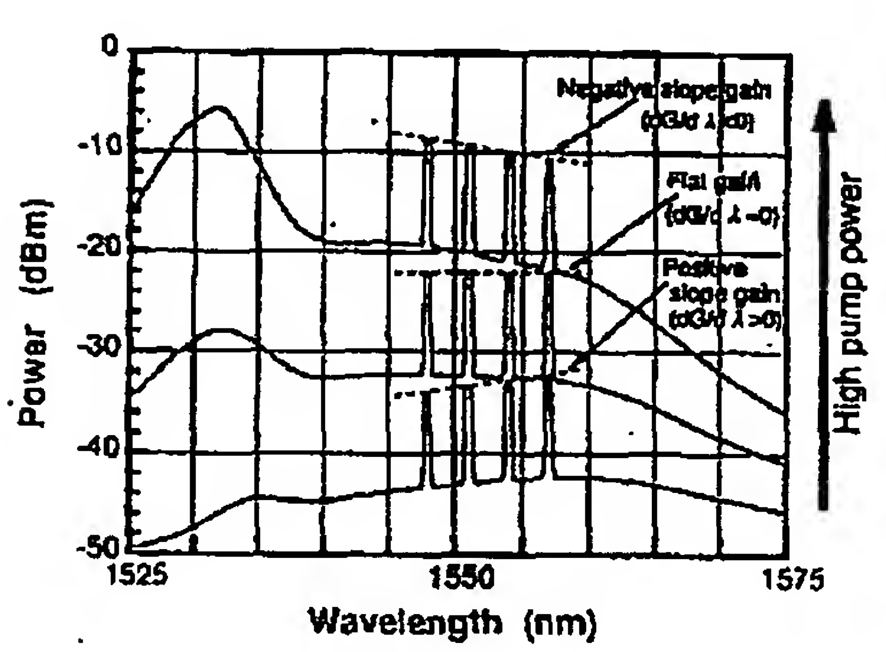


[Drawing 17]

図１６に示した光可変減衰器の磁気回路の変更例
（A）は上から見た断面図、（B）は横から見た断面図

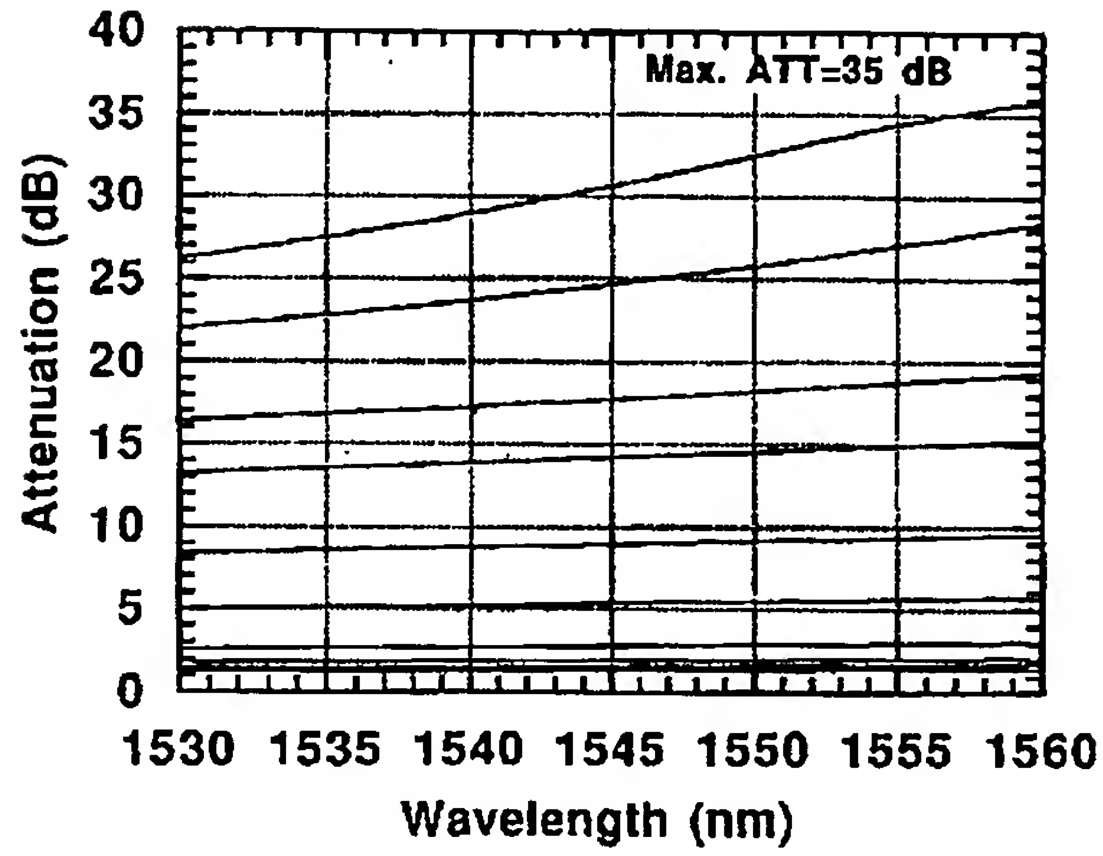


[Drawing 19]
典型的なＥＤＦＡの増幅特性

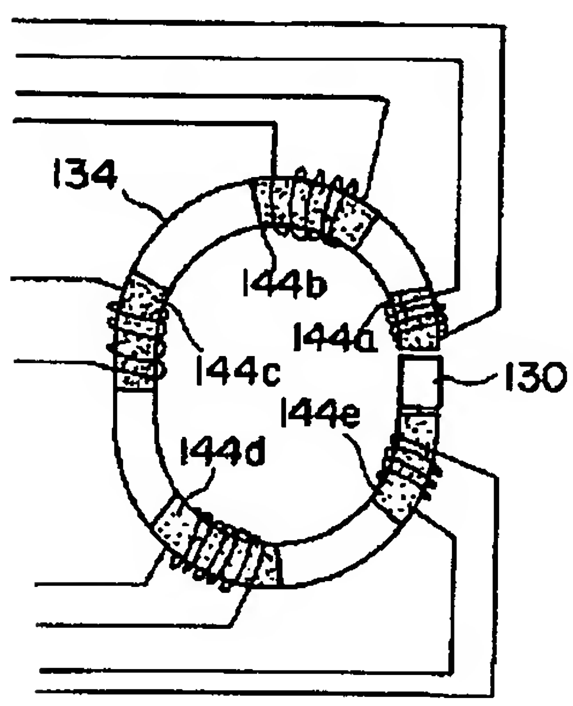


[Drawing 21]

光ファイバ増幅器の波長依存性をキャンセルするために
調整された光可変減衰器の減衰特性

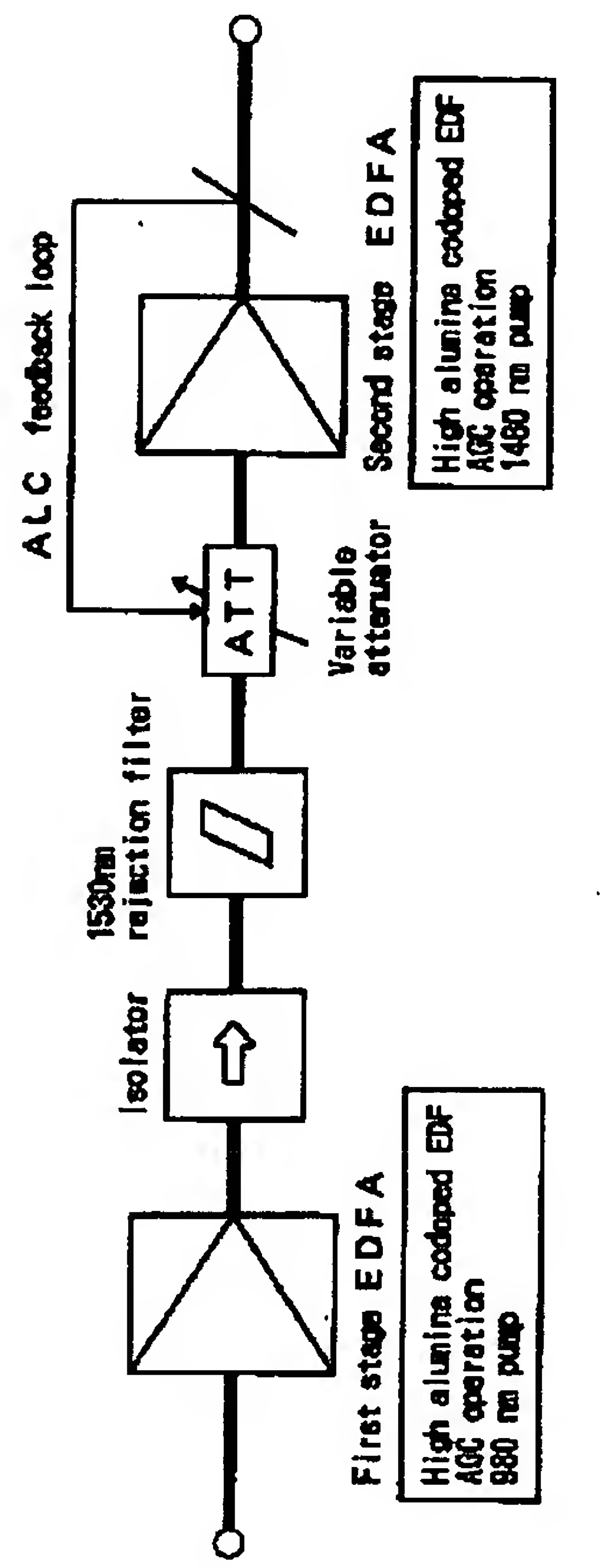


[Drawing 25]
本発明に係わる光可変減衰器に使用する
電磁石の構成を示す図



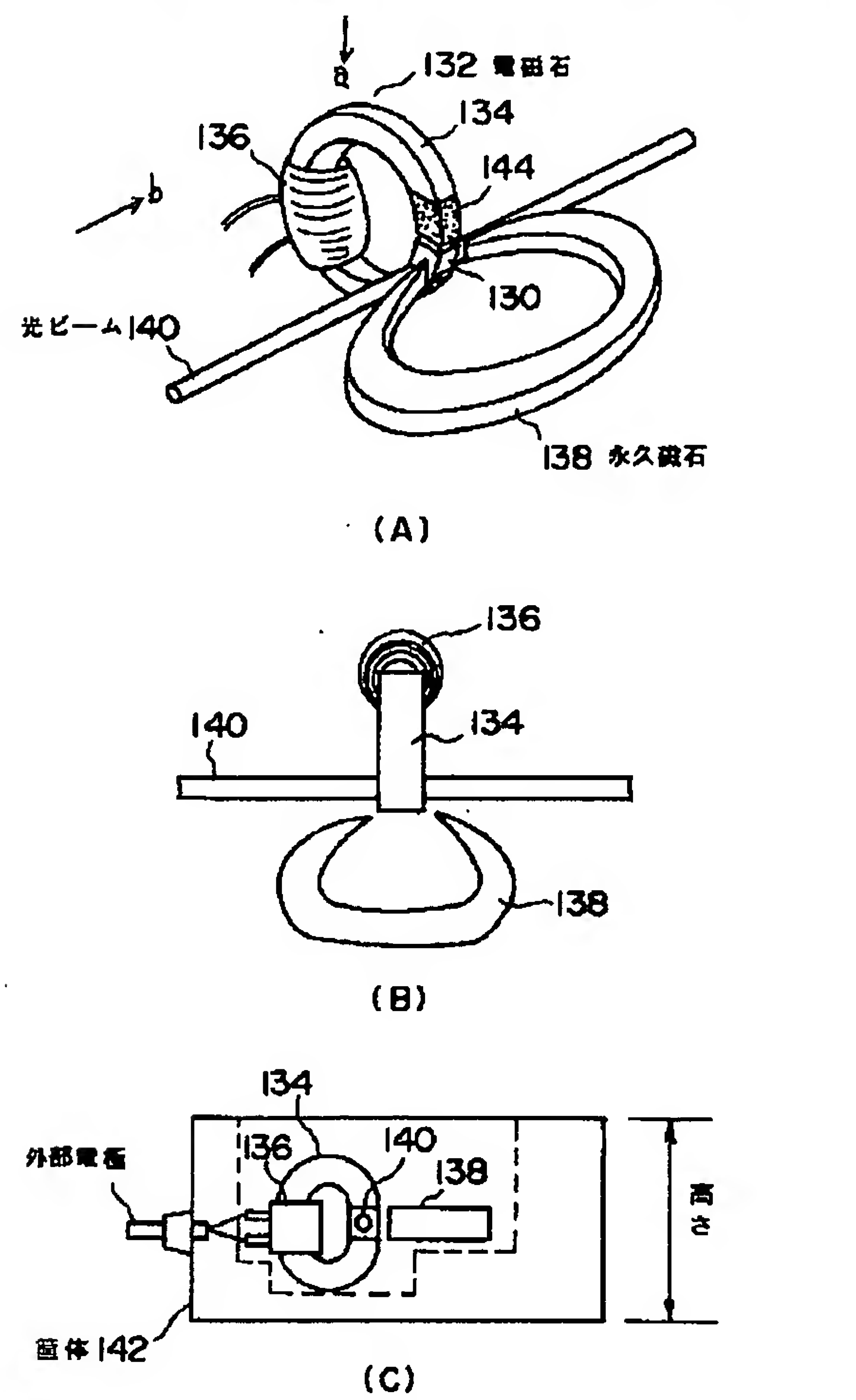
[Drawing 20]

光可変減衰器が組み込まれた光伝送装置の構成例



[Drawing 24]

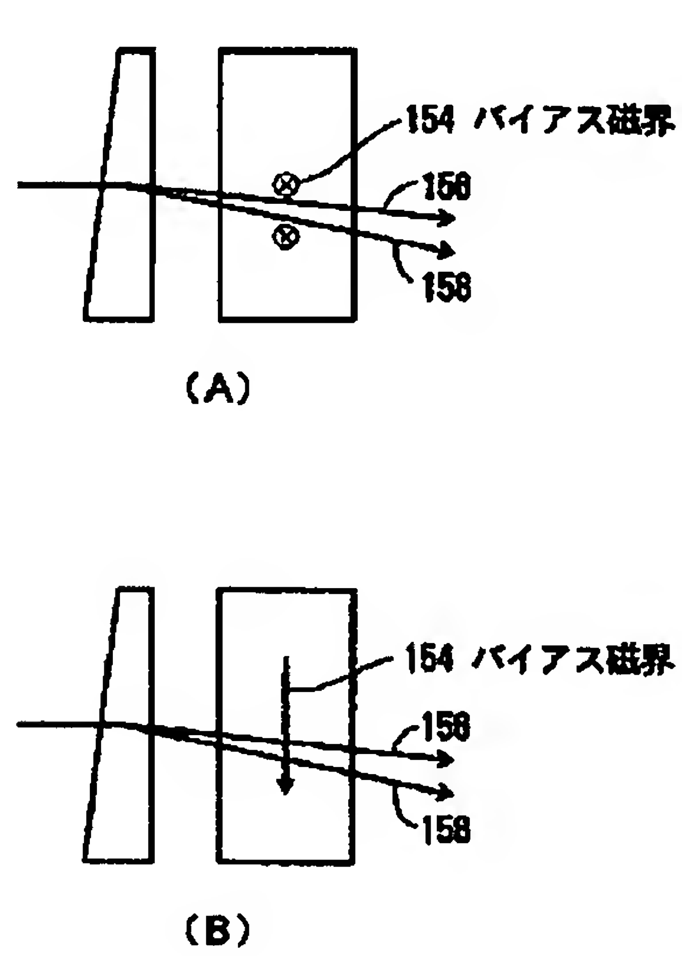
本発明に係わる光可変減衰器の第6の原理を説明するための構成例。(A)は外観図、(B)は、上面図、(C)は、正面図



[Drawing 27]

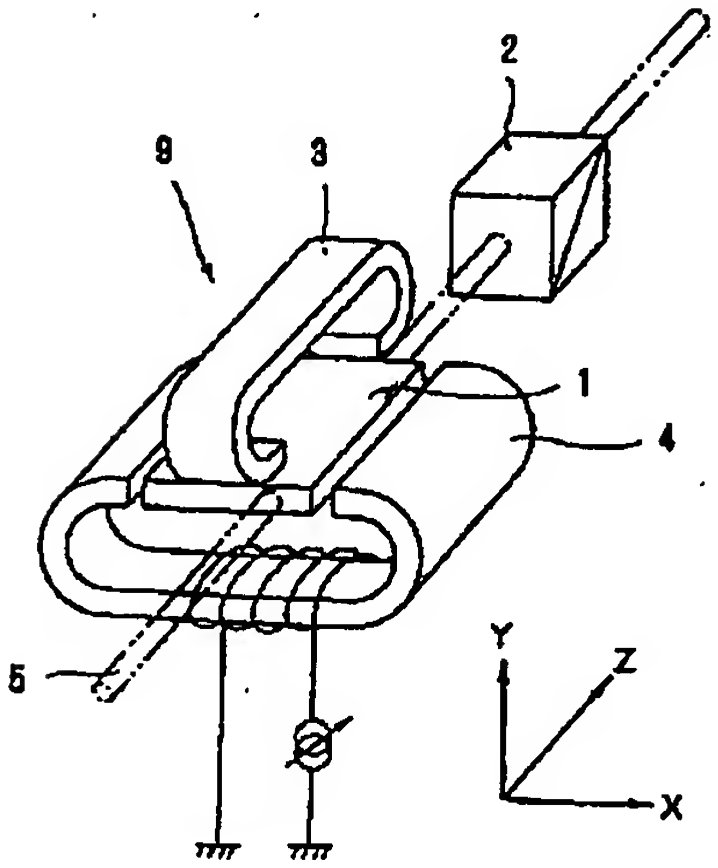
本発明に係わる光可変減衰器の第7の原理を説明するための

バイアス磁界の方向パターンを示す図



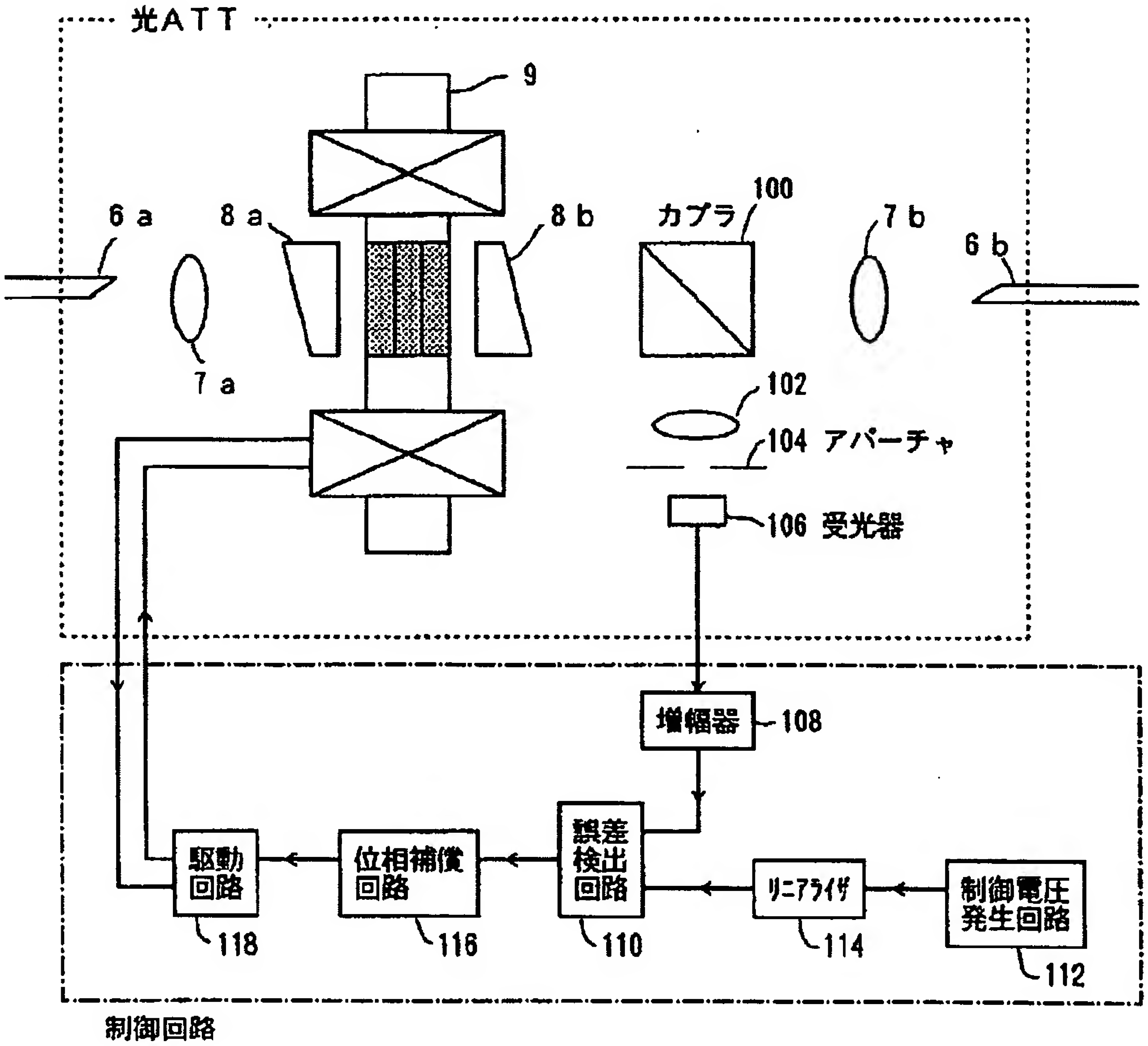
[Drawing 29]

従来の光可変減衰器の第１の構成例



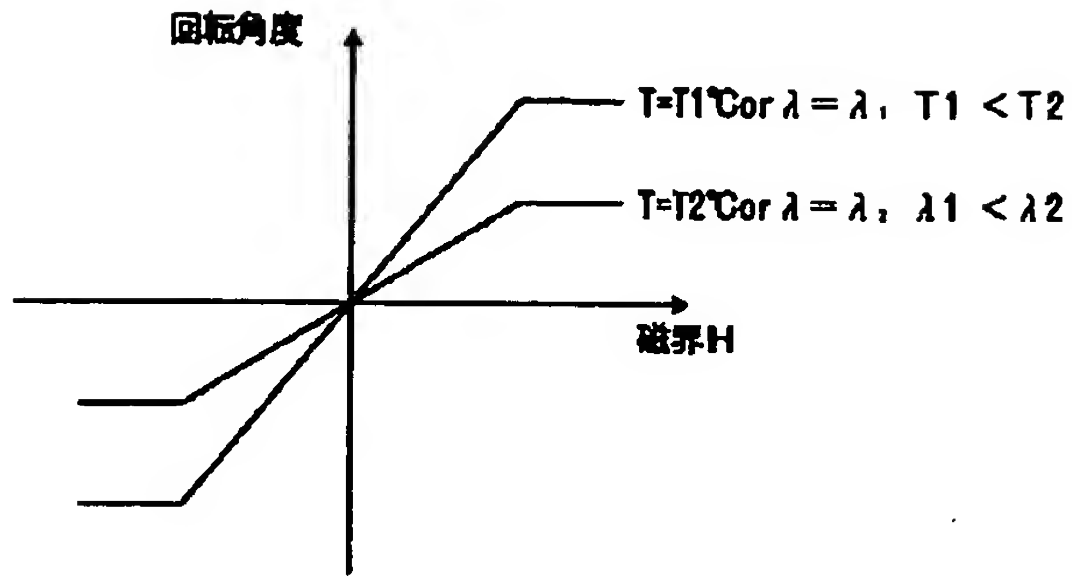
[Drawing 22]

本発明に係わる光可変減衰器の第５の原理を説明するための構成例



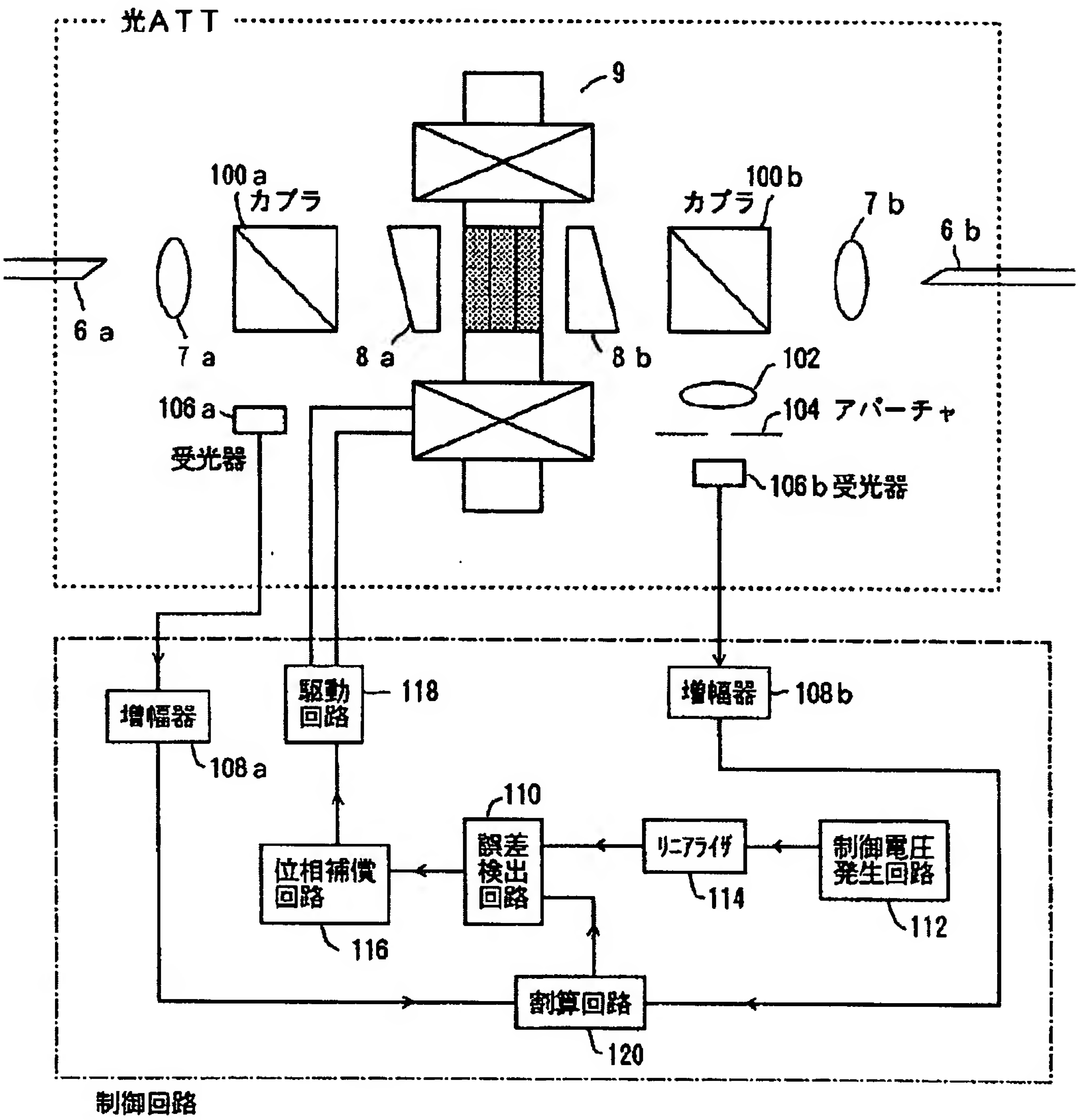
[Drawing 31]

磁界Hとファラデー回転角との関係



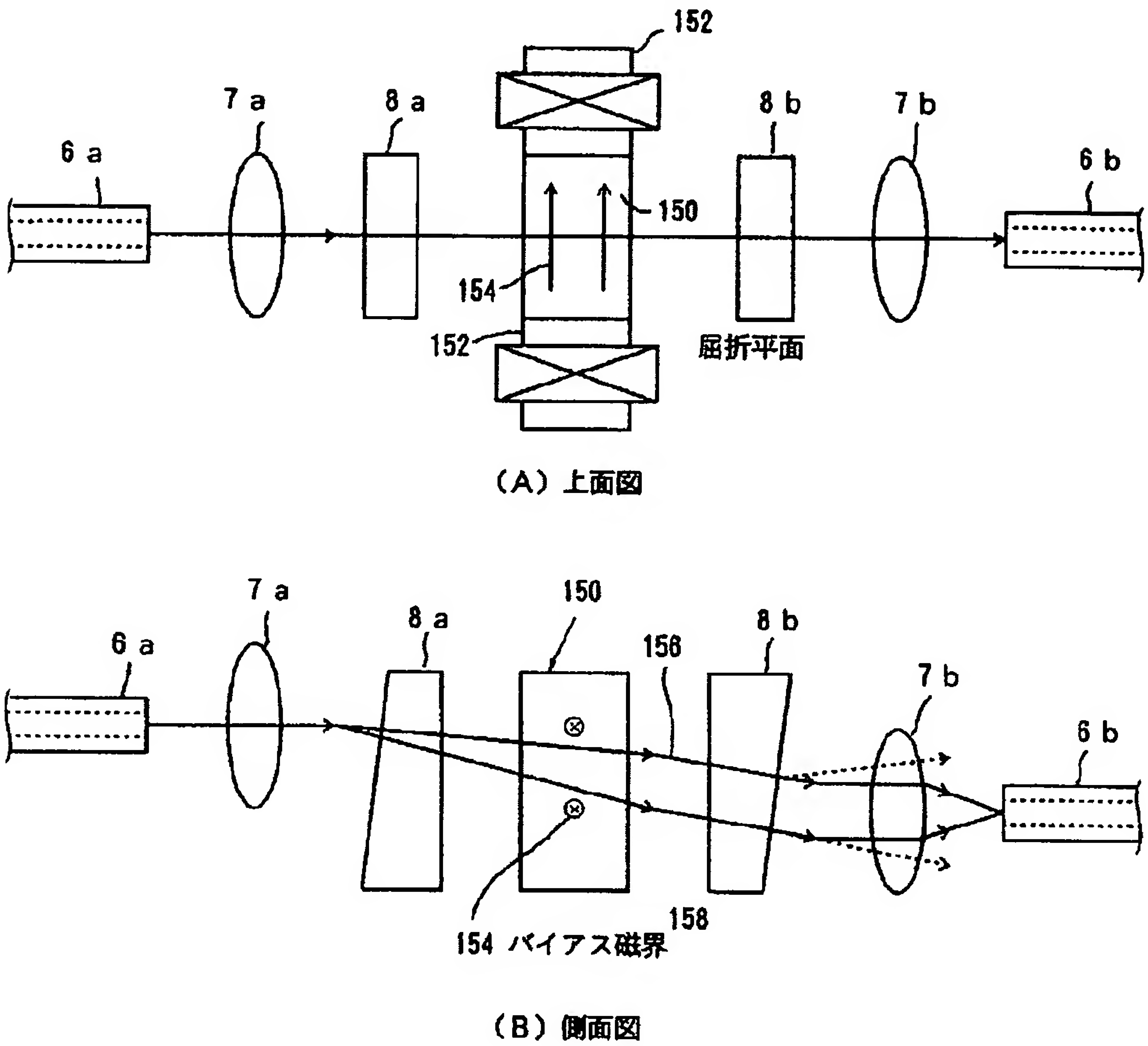
[Drawing 23]

図22に示す光可変減衰器の変更例



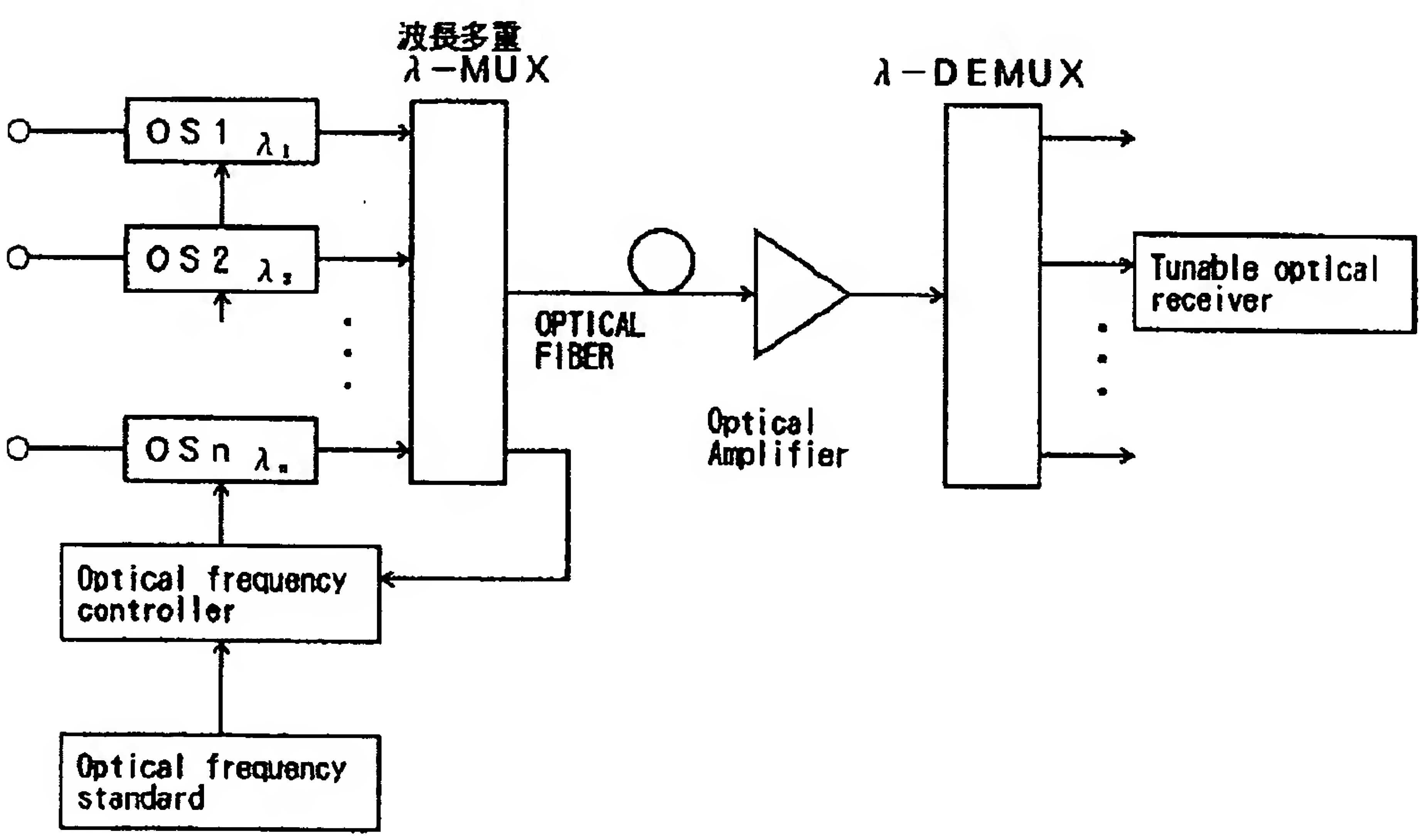
[Drawing 26]

本発明に係わる光可変減衰器の第７の原理を説明するための構成例



[Drawing 28]

典型的な波長多重通信方式のシステム構成図



[Translation done.]

* NOTICES *

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1. This document has been translated by computer.So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3.In the drawings, any words are not translated.

CORRECTION or AMENDMENT

[Official Gazette Type] Printing of amendment by the convention of 2 of Article 17 of patent law.
[Section partition] The 2nd partition of the 6th section.
[Date of issue] February 13, Heisei 15 (2003. 2.13)

[Publication No.] JP,9-236784,A.
[Date of Publication] September 9, Heisei 9 (1997. 9.9)
[**** format] Open patent official report 9-2368.
[Filing Number] Japanese Patent Application No. 8-45231.
[The 7th edition of International Patent Classification]

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G02F     1/09     505        .
1/35      501         .
H04B    10/152              .
10/142                .
10/04                 .
10/06                 .
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[FI]

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G02F     1/09     505        .
1/35      501         .
H04B     9/00         L      .
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[Procedure revision]
[Filing Date] November 12, Heisei 14 (2002. 11.12)
[Procedure amendment 1]
[Document to be Amended] Specification.
[Item(s) to be Amended] Claim.
[Method of Amendment] Change.
[Proposed Amendment]
[Claim(s)]
[Claim 1] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
It is the optical variable attenuator which has the analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction, and is characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state substantially with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal.
[Claim 2] It is the optical variable attenuator according to claim 1 which has further the polarizer which generates the aforementioned light beam, and is characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state as substantially as the polarization direction of the aforementioned polarizer.
[Claim 3] The polarization direction of the aforementioned analyzer and the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal are an optical variable attenuator according to claim 1 or 2 characterized by being set up at the angle of **30 degrees 80 degrees.

[Claim 4] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal,
It is the optical variable attenuator characterized by it being prepared in either the interior of the aforementioned magnetic circuit, or near, and having the permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal in parallel, impressing a magnetic field to the aforementioned magneto optics crystal even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost, and penetrating a part of aforementioned light beam [at least].
[Claim 5] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal,
It is the optical variable attenuator characterized by having the permanent magnet which generates the bias magnetic field impressed to the aforementioned magneto optics crystal at an angle smaller than 90 degrees, impressing a magnetic field to the aforementioned magneto optics crystal even when the magnetic field generated electrically at the aforementioned magnetic circuit is lost, and penetrating a part of aforementioned light beam [at least] as substantially as the magnetic field electrically generated in the aforementioned magnetic circuit.
[Claim 6] It is the optical variable attenuator according to claim 4 or 5 which has further the analyzer which passes the light beam which passed the aforementioned magneto optics crystal according to the polarization direction, and is characterized by setting the polarization direction of the aforementioned analyzer as a rectangular state substantially with the polarization direction of the aforementioned light beam in case there is no rotation of the polarization direction in the aforementioned magneto optics crystal.
[Claim 7] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The optical variable attenuator characterized by impressing efficiently the magnetic field which generated the magnetic field for being impressed by the aforementioned magneto optics crystal, has the magnetic circuit which has the yoke with which the aforementioned magneto optics crystal was inserted in the internal gap, and was generated in the yoke of the aforementioned magnetic circuit to the aforementioned magneto optics crystal.
[Claim 8] The aforementioned magnetic circuit is an optical variable attenuator according to claim 7 characterized by having further at least one coil for being prepared near the gap of the aforementioned yoke and making the aforementioned gap generate a magnetic field electrically.
[Claim 9] The optical variable attenuator according to claim 7 which it has further the 1st lens for converging the aforementioned light beam and carrying out incidence to the aforementioned magneto optics crystal, and the interval of the gap of the aforementioned yoke is narrowed according to the size of the light beam which it converged with the 1st lens of the above, and is characterized by impressing efficiently the magnetic field generated about this gap to the aforementioned magneto optics crystal.
[Claim 10] The optical variable attenuator according to claim 9 characterized by including the 2nd lens for setting the light beam by which convergence was carried out [aforementioned] as a predetermined size after the light beam by which convergence was carried out [aforementioned] passes the aforementioned magneto optics crystal.
[Claim 11] It is the light amplifier which amplifies the lightwave signal which has a predetermined wavelength-range region.
The light amplifier which has a gain property with a wavelength dependency,
It is the light amplifier characterized by reducing the aforementioned wavelength dependency of the gain in the aforementioned light amplifier while decreasing this lightwave signal in adjustable using rotation of the polarization direction of the lightwave signal in a magneto optics crystal, a damping property's having the aforementioned wavelength dependency of the gain in the aforementioned light amplifier, and the optical variable attenuator which has a reverse wavelength dependency substantially and the aforementioned lightwave signal's declining in the aforementioned optical variable attenuator.
[Claim 12] The aforementioned optical variable attenuator,
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned lightwave signal,
It is the light amplifier according to claim 11 which has the analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction, and is characterized by setting up the

polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal so that the wavelength dependency of the aforementioned reverse may be substantially acquired in the predetermined magnitude of attenuation.
[Claim 13] It is an optical variable attenuator for connecting with a light amplifier, and reducing the wavelength dependency of the gain in the aforementioned light amplifier, and decreasing a lightwave signal.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned lightwave signal,
It is the optical variable attenuator which has the analyzer which passes the lightwave signal which passed the aforementioned magneto optics crystal according to the polarization direction, and is characterized by setting up the polarization direction of the aforementioned analyzer, the polarization direction of the aforementioned lightwave signal, and the aforementioned magneto optics crystal so that a reverse wavelength dependency may be substantially acquired with the wavelength dependency of the gain of the aforementioned light amplifier in the predetermined magnitude of attenuation.
[Claim 14] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator,
The optical variable attenuator characterized by controlling the polarization direction of the aforementioned light beam in the aforementioned magneto optics crystal so that it may have the output side electric eye which branches a part of output light of the aforementioned optical variable attenuator, and carries out the monitor of the output power and the output power of the aforementioned optical variable attenuator which carried out the monitor by the aforementioned output side electric eye may become a predetermined value.
[Claim 15] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The analyzer which leads a part of light beam [at least] which passed the aforementioned magneto optics crystal to the output of the aforementioned optical variable attenuator,
The input-side electric eye which carries out the monitor of the input control power of the light beam inputted into the aforementioned magneto optics crystal,
The optical variable attenuator characterized by controlling the polarization direction of the aforementioned light beam in the aforementioned magneto optics crystal so that it may have the output side electric eye which carries out the monitor of the output power of the aforementioned optical variable attenuator and a ratio with the output power of the aforementioned optical variable attenuator which carried out the monitor by the input control power and the aforementioned output side electric eye of the aforementioned light beam which carried out the monitor by the aforementioned input-side electric eye may become a predetermined value.
[Claim 16] the aforementioned analyzer -- a birefringence crystal -- containing -- the aforementioned analyzer **** -- the optical variable attenuator according to claim 14 or 15 characterized by having further the aperture which leads a part of light beam by which the separation chip box was carried out in polarization to the aforementioned output side electric eye
[Claim 17] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The magnetic circuit which generates the magnetic field for being impressed by the aforementioned magneto optics crystal about an internal gap,
It is the optical variable attenuator which has a case for holding the aforementioned magneto optics crystal and the aforementioned magnetic circuit, and mounting in a substrate, and is characterized by mounting the aforementioned magnetic circuit in a case so that the direction of the aforementioned gap may be the height direction of the aforementioned case substantially.
[Claim 18] It is the optical variable attenuator which decreases the power of a light beam.
The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,
The optical variable attenuator characterized by having the aforementioned magnetic circuit which is close so that the aforementioned point may sandwich the aforementioned magneto optics crystal including the yoke of a horseshoe shape configuration with which it is the magnetic circuit which generates the magnetic field for being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and the front point is thinner than other portions.
[Claim 19] It is the optical variable attenuator according to claim 18 which the aforementioned magnetic circuit consists of permanent magnets, and has further the electromagnet which generates electrically the magnetic field for

being approached and put on the aforementioned magneto optics crystal, and being impressed by the aforementioned magneto optics crystal, and is characterized by the point of the yoke of the aforementioned permanent magnet being close from the aforementioned electromagnet with the aforementioned magneto optics crystal.

[Claim 20] It is the optical variable attenuator which decreases the power of a light beam.

The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,

It is the optical variable attenuator characterized by maintaining the aforementioned magnetic field even if it has the yoke which contains the half-hard magnetic substance in part at least, it has the magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal by drive current and supply of the aforementioned drive current stops.

[Claim 21] The aforementioned yoke is an optical variable attenuator according to claim 20 characterized by the ability to change gradually the size of the magnetic field generated in the aforementioned magnetic circuit by having partially two or more half-hard magnetic substance with which the magnetization in a saturation state differs, and controlling magnetization for every aforementioned half hard magnetic substance.

[Claim 22] It is the optical variable attenuator which decreases the power of a light beam.

The 1st wedge-like birefringence crystal which performs polarization separation of the aforementioned light beam,

The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam where polarization was separated as the wedge-like birefringence crystal of the above 1st,

The magnetic circuit which generates the magnetic field for being substantially impressed by the aforementioned magneto optics crystal perpendicularly with the aforementioned light beam,

The optical variable attenuator characterized by impressing the magnetic field of the aforementioned magnetic circuit to the flat surface which consists of aforementioned light beams from which it has the 2nd wedge-like birefringence crystal to which the birefringence of the light beam outputted from the aforementioned magneto optics crystal is carried out, and polarization was separated as the wedge-like birefringence crystal of the above 1st perpendicularly substantially at the aforementioned magneto optics crystal.

[Claim 23] It is the optical variable attenuator which decreases the power of a light beam.

The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,

The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal in parallel to the optical path of the aforementioned light beam,

It is prepared in either the interior of the aforementioned magnetic circuit, or near, and has the permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal perpendicularly. Rotation is given in the polarization direction of the light beam which penetrates the aforementioned magneto optics crystal by the magnetic field by which the magnetic field generated by the aforementioned magnetic circuit and the magnetic field generated with the aforementioned permanent magnet were compounded. The optical variable attenuator characterized by not giving rotation in the polarization direction of the light which penetrates the aforementioned magneto optics crystal even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost.

[Claim 24] It is the optical variable attenuator which decreases the power of a light beam.

The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,

The magnetic circuit which generates electrically the magnetic field for impressing in the direction which intersects perpendicularly to the optical path of the aforementioned light beam at the aforementioned magneto optics crystal,

Are prepared in either the interior of the aforementioned magnetic circuit, or near, and to the aforementioned optical path, it is parallel and has the permanent magnet which generates the bias magnetic field impressed to the aforementioned magneto optics crystal so that it may become perpendicular substantially with the magnetic field electrically generated in the aforementioned magnetic circuit. Rotation is given in the polarization direction of the light beam which penetrates the aforementioned magneto optics crystal by the magnetic field by which the magnetic field generated by the aforementioned magnetic circuit and the magnetic field generated with the aforementioned permanent magnet were compounded. The optical variable attenuator characterized by giving rotation in the polarization direction of the light which penetrates the aforementioned magneto optics crystal even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost.

[Claim 25] It is the optical variable attenuator which decreases the power of a light beam.

The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam,

The magnetic circuit which consists of the yoke and coil which generate electrically the magnetic field for being impressed by the aforementioned magneto optics crystal in parallel to the optical path of the aforementioned light beam,

It is included in the aforementioned yoke, or is prepared near the yoke, and has the permanent magnet which generates

the bias magnetic field impressed to the aforementioned magneto optics crystal in parallel to the aforementioned optical path.

The aforementioned magnetic circuit is an optical variable attenuator characterized by passing current in the aforementioned coil and forming a magnetic field which negates the aforementioned bias magnetic field.

[Procedure amendment 2]

[Document to be Amended] Specification.

[Item(s) to be Amended] 0039.

[Method of Amendment] Change.

[Proposed Amendment]

[0039] The 1st wedge-like birefringence crystal to which it is the optical variable attenuator which decreases the power of a light beam, and the birefringence of the aforementioned light beam is carried out with invention equipment according to claim 22, The magneto optics crystal which makes adjustable rotate the polarization direction of the aforementioned light beam where polarization was separated as the wedge-like birefringence crystal of the above 1st, The magnetic circuit which generates the magnetic field for being substantially impressed by the aforementioned magneto optics crystal perpendicularly with the aforementioned light beam, It has the 2nd wedge-like birefringence crystal to which the birefringence of the light beam outputted from the aforementioned magneto optics crystal is carried out. It is characterized by impressing the magnetic field of the aforementioned magnetic circuit to the flat surface which consists of aforementioned light beams from which polarization was separated as the wedge-like birefringence crystal of the above 1st perpendicularly substantially at the aforementioned magneto optics crystal. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 23, The magnetic circuit which generates electrically the magnetic field for being impressed by the aforementioned magneto optics crystal in parallel to the optical path of the aforementioned light beam, It is prepared in either the interior of the aforementioned magnetic circuit, or near, and has the permanent magnet which generates the magnetic field electrically generated in the aforementioned magnetic circuit, and the bias magnetic field substantially impressed to the aforementioned magneto optics crystal perpendicularly. Rotation is given in the polarization direction of the light beam which penetrates the aforementioned magneto optics crystal by the magnetic field by which the magnetic field generated by the aforementioned magnetic circuit and the magnetic field generated with the aforementioned permanent magnet were compounded. Even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost, it is characterized by not giving rotation in the polarization direction of the light which penetrates the aforementioned magneto optics crystal. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 24, The magnetic circuit which generates electrically the magnetic field for impressing in the direction which intersects perpendicularly to the optical path of the aforementioned light beam at the aforementioned magneto optics crystal, Are prepared in either the interior of the aforementioned magnetic circuit, or near, and to the aforementioned optical path, it is parallel and has the permanent magnet which generates the bias magnetic field impressed to the aforementioned magneto optics crystal so that it may become perpendicular substantially with the magnetic field electrically generated in the aforementioned magnetic circuit. Rotation is given in the polarization direction of the light beam which penetrates the aforementioned magneto optics crystal by the magnetic field by which the magnetic field generated by the aforementioned magnetic circuit and the magnetic field generated with the aforementioned permanent magnet were compounded. Even when the magnetic field electrically generated in the aforementioned magnetic circuit is lost, it is characterized by giving rotation in the polarization direction of the light which penetrates the aforementioned magneto optics crystal. The magneto optics crystal which it is [magneto optics crystal] the optical variable attenuator which decreases the power of a light beam, and makes adjustable rotate the polarization direction of the aforementioned light beam with invention equipment according to claim 25, The magnetic circuit which consists of the yoke and coil which generate electrically the magnetic field for being impressed by the aforementioned magneto optics crystal in parallel to the optical path of the aforementioned light beam, It is included in the aforementioned yoke, or is prepared near the yoke, and has the permanent magnet which generates the bias magnetic field impressed to the aforementioned magneto optics crystal in parallel to the aforementioned optical path. the aforementioned magnetic circuit It is characterized by passing current in the aforementioned coil and forming a magnetic field which negates the aforementioned bias magnetic field.

[Procedure amendment 3]

[Document to be Amended] Specification.

[Item(s) to be Amended] 0016.

[Method of Amendment] Change.
[Proposed Amendment]
[0016] Moreover, in the 2nd example of composition of the conventional optical variable attenuator shown in drawing 30, the loss (Polarization Dependent Loss:PDL) by few polarization dependencies has still arisen. In view of the above-mentioned trouble, the purpose of this invention reduces the temperature dependence, the wavelength dependency, and drive current of the magnitude of attenuation, and provides an optical transmission device with the small optical variable attenuator using the applicable magneto optics crystal easily.
[Procedure amendment 4]
[Document to be Amended] Specification.
[Item(s) to be Amended] 0042.
[Method of Amendment] Change.
[Proposed Amendment]
[0042] Therefore, the wavelength dependency of the magnitude of attenuation can be reduced in a **** variable attenuator. Moreover, the temperature dependence of the magnitude of attenuation can be reduced similarly. In the optical variable attenuator given in any 1 term, the magnetic field generated with the permanent magnet or its part is always impressed to a light beam and parallel at the magneto optics crystal a claim 4 or among 6. Therefore, in a **** variable attenuator, even if the current impressed to a magnetic circuit will not flow by failure etc., a light beam can be penetrated. Consequently, the influence which it has on operation of transmission equipment can be reduced. Furthermore, wavelength and temperature dependence can also be reduced.
[Procedure amendment 5]
[Document to be Amended] Specification.
[Item(s) to be Amended] 0047.
[Method of Amendment] Change.
[Proposed Amendment]
[0047] A claim 14 or among 16, it is controlled, or it is controlled so that a ratio with the output power of the optical variable attenuator which carried out the monitor by the power and the output side electric eye of the light beam which carried out the monitor by the input-side electric eye becomes a predetermined value so that the output power of the optical variable attenuator which carried out the monitor by the output side electric eye in the optical variable attenuator given in any 1 term becomes a predetermined value. Therefore, amendment of the temperature characteristic of the magnitude of attenuation of an optical variable attenuator, degradation with the passage of time, polarization loss change, etc. is attained.
[Procedure amendment 6]
[Document to be Amended] Specification.
[Item(s) to be Amended] 0050.
[Method of Amendment] Change.
[Proposed Amendment]
[0050] In an optical variable attenuator according to claim 21, the magnetic field generated with an electromagnet can be stably set up gradually by controlling two or more half-hard magnetic substance with which magnetization differs. In an optical variable attenuator according to claim 22, the bias magnetic field for simplifying the magnetic domain of a magneto optics crystal is substantially impressed perpendicularly by the refraction flat surface. Thereby, polarization dependency loss can be reduced. In a claim 23 and an optical variable attenuator given in 24, even if it is the case where the magnetic field electrically generated by setting up the direction of the bias magnetic field by the permanent magnet stops by failure etc. according to the polarization direction of an analyzer, a light beam can be penetrated. In the optical variable attenuator according to claim 25, a permanent magnet is built into a yoke or it is prepared near the yoke. Therefore, even if the current impressed to a coil stops by failure etc., the seal of approval of the magnetic field is carried out in parallel with a magneto optics crystal. Therefore, a light beam can be penetrated and wavelength and temperature dependence can also be reduced.
[Procedure amendment 7]
[Document to be Amended] Specification.
[Item(s) to be Amended] 0139.
[Method of Amendment] Change.
[Proposed Amendment]
[0139] A claim 14 or among 16, it is controlled, or it is controlled so that a ratio with the output power of the optical variable attenuator which carried out the monitor by the power and the output side electric eye of the light beam which carried out the monitor by the input-side electric eye becomes a predetermined value so that the output power of the

optical variable attenuator which carried out the monitor by the output side electric eye in the optical variable attenuator given in any 1 term becomes a predetermined value. Therefore, amendment of the temperature characteristic of the magnitude of attenuation of an optical variable attenuator, degradation with the passage of time, polarization loss change, etc. is attained.
[Procedure amendment 8]
[Document to be Amended] Specification.
[Item(s) to be Amended] 0142.
[Method of Amendment] Change.
[Proposed Amendment]
[0142] In an optical variable attenuator according to claim 21, the magnetic field generated with an electromagnet can be stably set up gradually by controlling two or more half-hard magnetic substance with which magnetization differs. In an optical variable attenuator according to claim 22, the bias magnetic field for simplifying the magnetic domain of a magneto optics crystal is substantially impressed perpendicularly by the refraction flat surface. Thereby, polarization dependency loss can be reduced. In a claim 23 and an optical variable attenuator given in 24, even if it is the case where the magnetic field electrically generated by setting up the direction of the bias magnetic field by the permanent magnet stops by failure etc. according to the polarization direction of an analyzer, a light beam can be penetrated. In the optical variable attenuator according to claim 25, a permanent magnet is built into a yoke or it is prepared near the yoke. Therefore, even if the current impressed to a coil stops by failure etc., the seal of approval of the magnetic field is carried out in parallel with a magneto optics crystal. Therefore, a light beam can be penetrated and wavelength and temperature dependence can also be reduced.

[Translation done.]

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Ｈ０４Ｂ	10/152			Ｈ０４Ｂ	9/00	Ｌ	
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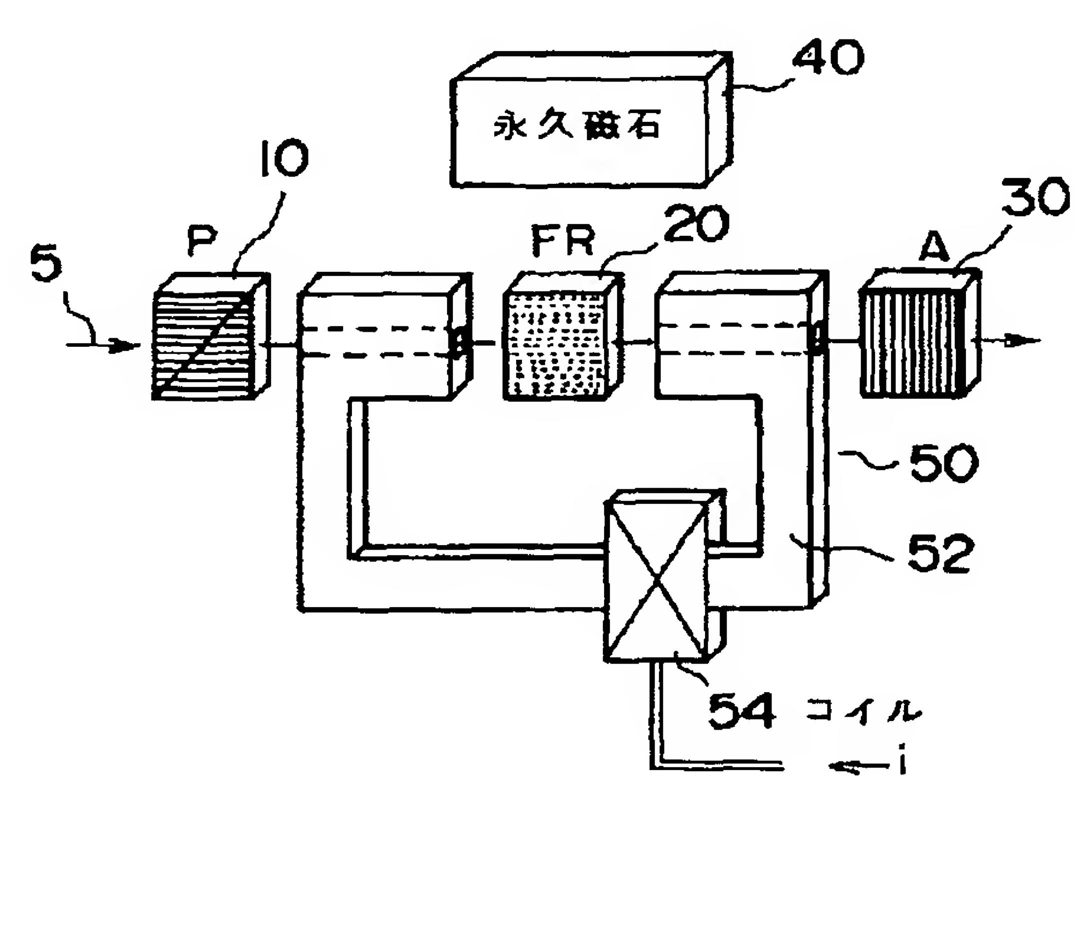
(54)【発明の名称】　光可変減衰器

(57)【要約】

【課題】　減衰量の温度依存性や波長依存性、及び駆動電流を低減し、光伝送装置に容易に適用可能な磁気光学結晶を用いた小型な光可変減衰器を提供する。

【解決手段】　光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光ビームをその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されている。

本発明に係わる光可変減衰器の構成例



【特許請求の範囲】

【請求項１】　光ビームのパワーを減衰する光可変減衰器であって、
前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶を通過した光ビームをその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されていることを特徴とする光可変減衰器。

【請求項２】　前記光ビームを発生する偏光子をさらに有し、前記検光子の偏光方向は、前記偏光子の偏光方向と実質的に直交状態に設定されていることを特徴とする請求項１記載の光可変減衰器。

【請求項３】　前記検光子の偏光方向と、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向とは、８０度±３０度の角度で設定されていることを特徴とする請求項１又は２記載の光可変減衰器。

【請求項４】　光ビームのパワーを減衰する光可変減衰器であって、
前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶に印加するための磁界を電気的に発生する磁気回路と、
前記磁気回路の内部及び近傍のどちらかに設けられ、前記磁気回路で電気的に発生する磁界と実質的に平行に前記磁気光学結晶に印加されるバイアス磁界を発生する永久磁石とを有し、前記磁気回路で電気的に発生する磁界が失われた場合でも、前記磁気光学結晶に磁界が印加され前記光ビームの少なくとも一部は透過されることを特徴とする光可変減衰器。

【請求項５】　光ビームのパワーを減衰する光可変減衰器であって、
前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶に印加するための磁界を電気的に発生する磁気回路と、
前記磁気回路で電気的に発生する磁界と実質的に９０度より小さい角度で前記磁気光学結晶に印加されるバイアス磁界を発生する永久磁石とを有し、前記磁気回路で電気的に発生する磁界が失われた場合でも、前記磁気光学結晶に磁界が印加され前記光ビームの少なくとも一部は透過されることを特徴とする光可変減衰器。

【請求項６】　前記磁気光学結晶を通過した光ビームをその偏光方向に応じて通過させる検光子をさらに有し、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されていることを特徴とする請求項４又は５記載の光可変減衰器。

【請求項７】　光ビームのパワーを減衰する光可変減衰器であって、
前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶に印加するための磁界を発生し、内部のギャップに前記磁気光学結晶が挿入されたヨークを有する磁気回路とを有し、前記磁気回路のヨークで発生された磁界が効率良く前記磁気光学結晶に印加されることを特徴とする光可変減衰器。

【請求項８】　前記磁気回路は、前記ヨークのギャップの近傍に設けられ前記ギャップに磁界を電気的に発生させるための少なくとも１つのコイルをさらに有することを特徴とする請求項７記載の光可変減衰器。

【請求項９】　前記光ビームを収束して前記磁気光学結晶に入射するための第１のレンズをさらに有し、前記第１のレンズによって収束された光ビームのサイズに応じて前記ヨークのギャップの間隔が狭くされ、該ギャップに発生する磁界を前記磁気光学結晶に効率よく印加することを特徴とする請求項７記載の光可変減衰器。

【請求項１０】　前記収束された光ビームが前記磁気光学結晶を通過した後、前記収束された光ビームを所定の大きさに設定するための第２のレンズを含むことを特徴とする請求項９記載の光可変減衰器。

【請求項１１】　所定の波長帯域を有する光信号を増幅する光増幅装置であって、
波長依存性がある利得特性を有する光増幅器と、
磁気光学結晶における光信号の偏光方向の回転を用いて該光信号を可変的に減衰し、減衰特性は前記光増幅器における利得の前記波長依存性と実質的に逆の波長依存性を有する光可変減衰器とを有し、前記光可変減衰器において、前記光信号が減衰されると共に、前記光増幅器における利得の前記波長依存性が低減されることを特徴とする光増幅装置。

【請求項１２】　前記光可変減衰器は、
前記光信号の偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶を通過した光信号をその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向、前記光信号の偏光方向、及び前記磁気光学結晶は、所定の減衰量において、前記逆の波長依存性が実質的に得られるように設定されていることを特徴とする請求項１１記載の光増幅装置。

【請求項１３】　光増幅器に接続され前記光増幅器における利得の波長依存性を低減しかつ光信号を減衰するための光可変減衰器であって、
前記光信号の偏光方向を可変に回転させる磁気光学結晶と、
前記磁気光学結晶を通過した光信号をその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向、前記光信号の偏光方向、及び前記磁気光学結晶は、

所定の減衰量において、前記光増幅器の利得の波長依存性と実質的に逆の波長依存性が得られるように設定されていることを特徴とする光可変減衰器。

【請求項１４】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

前記磁気光学結晶を通過した光ビームの少なくとも一部を前記光可変減衰器の出力に導く検光子と、

前記光可変減衰器の出力光を一部分岐して出力パワーをモニタする出力側受光器とを有し、前記出力側受光器でモニタした前記光可変減衰器の出力パワーが所定の値になるように、前記磁気光学結晶における前記光ビームの偏光方向が制御されることを特徴とする光可変減衰器。

【請求項１５】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

前記磁気光学結晶を通過した光ビームの少なくとも一部を前記光可変減衰器の出力に導く検光子と、

前記磁気光学結晶に入力される光ビームの入力パワーをモニタする入力側受光器と、

前記光可変減衰器の出力パワーをモニタする出力側受光器とを有し、前記入力側受光器でモニタした前記光ビームの入力パワーと前記出力側受光器でモニタした前記光可変減衰器の出力パワーとの比が所定の値になるように、前記磁気光学結晶における前記光ビームの偏光方向が制御されることを特徴とする光可変減衰器。

【請求項１６】　前記検光子は複屈折結晶を含み、前記検光子おいて偏光を分離折された光ビームの一部を前記出力側受光器に導くアパーチャをさらに有することを特徴とする請求項１４又は１５記載の光可変減衰器。

【請求項１７】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

前記磁気光学結晶に印加するための磁界を内部のギャップに発生する磁気回路と、

前記磁気光学結晶及び前記磁気回路を収容し基板に実装するための筐体とを有し、前記磁気回路は、前記ギャップの方向が実質的に前記筐体の高さ方向であるように筐体に実装されることを特徴とする光可変減衰器。

【請求項１８】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

前記磁気光学結晶に近接して置かれ前記磁気光学結晶に印加するための磁界を発生する磁気回路であって、前先端部が他の部分より細くなっている馬蹄形形状のヨークを含み前記先端部が前記磁気光学結晶を挟むように近接している前記磁気回路とを有することを特徴とする光可変減衰器。

【請求項１９】　前記磁気回路は永久磁石で構成され、また前記磁気光学結晶に近接して置かれ前記磁気光学結晶に印加するための磁界を電気的に発生する電磁石をさらに有し、前記永久磁石のヨークの先端部は、前記電磁石よりも前記磁気光学結晶により近接していることを特徴とする請求項１８記載の光可変減衰器。

【請求項２０】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

少なくとも一部に半硬質磁性体を含むヨークを有し、前記磁気光学結晶に印加するための磁界を駆動電流によって電気的に発生する磁気回路とを有し、前記駆動電流の供給が停止しても前記磁界は維持されることを特徴とする光可変減衰器。

【請求項２１】　前記ヨークは、飽和状態における磁化の異なる複数の半硬質磁性体を部分的に有し、前記半硬質磁性体毎に磁化を制御することによって前記磁気回路で発生する磁界の大きさを段階的に変更できることを特徴とする請求項２０記載の光可変減衰器。

【請求項２２】　光ビームのパワーを減衰する光可変減衰器であって、

前記光ビームの偏光分離を行う第１のウェッジ状複屈折結晶と、

前記第１のウェッジ状複屈折結晶で偏光を分離された前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、

前記磁気光学結晶に前記光ビームと実質的に垂直に印加するための磁界を発生する磁気回路と、

前記磁気光学結晶から出力される光ビームを複屈折させる第２のウェッジ状複屈折結晶とを有し、前記第１のウェッジ状複屈折結晶で偏光を分離された前記光ビームで構成される平面に実質的に垂直に、前記磁気回路の磁界が前記磁気光学結晶に印加されることを特徴とする光可変減衰器。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、光可変減衰器に関し、特に、磁気光学結晶を使用し、機械的な可動部分のない小型な光可変減衰器に関する。

【０００２】

【従来の技術】光通信システムにおいては、光強度（パワー）を必要に応じて調節する必要があり、そのため光可変減衰器が使用されている。従来の可変減衰器では、ガラス基板上に物質を透過光強度が連続的に変化するように付着され、ガラス基板上の透過位置を機械的に移動されて減衰量が変化される。従来の可変減衰器は、機械的な構造を有するため、信頼性が低い、応答速度が遅

い、形状の大型である等の問題を有していた。このため、このような光可変減衰器を、伝送装置に組み込むことは難しく、主に測定器として使用されてきた。

【０００３】近年、光ファイバ増幅器の技術が進展し、光強度を比較的簡単に増幅することが可能となってきている。このため、１本の光ファイバ中に波長の異なる多数の光を伝送させる波長多重通信方式の検討が行われている。図２８に、典型的な波長多重通信方式のシステム構成図を示す。光ファイバ増幅器を使用すれば、波長多重された複数の光信号を一括して増幅することが可能であり、経済的な光通信システムの構築が可能となる。

【０００４】光ファイバ増幅器を使用した波長多重通信システムでは、伝送信号の品質は光信号強度と雑音強度との比（光ＳＮＲ）で決定される。各光信号の光ＳＮＲを所定の値以上に保つためには、各光信号の光強度を揃える必要がある。各光信号のレベルは、光源（一般的には、レーザダイオード（ＬＤ）を使用）の出力パワーのばらつき、光源毎に備えられる各種光部品の挿入損失のばらつき等によって、ばらつく。さらに、光ファイバ増幅器も、利得の波長依存性を有し、光ファイバ増幅器を通過すると、各波長毎に光信号のパワーが変化する。このため、光信号のパワーのばらつきを調整し抑圧するための光可変減衰器を、光伝送装置内に組み込む必要がある。

【０００５】上記の目的のための光可変減衰器として、特開平６－５１２５５「光アッテネータ」が提案されている。図２９に、従来の光可変減衰器の第１の構成例を示す。この光可変減衰器は、磁気光学結晶（ｍａｇｎｅｔｏｏｐｔｉｃａｌ　ｃｙｒｉｓｔａｌ）１、偏光子　＊（ｐｏｌａｒｉｚｅｒ）２、磁気光学結晶１に光軸と平行に磁界を印加する第１の磁界印加手段３（この場合は、永久磁石が使用されている）、磁気光学結晶１に光軸と垂直に磁界を印加する第２の磁界印加手段４から構成されている。磁気光学結晶１と、第１の磁界印加手段３と、第２の磁界印加手段４とでファラデー回転子９を構成する。ここでは、第１の磁界印加手段３には、永久磁石が使用され、第２の磁界印加手段４には、印加電流によって発生磁界の強さを調整できる電磁石が使用されている。また、図示しない他の偏光子を通過した直線偏光の光ビーム５は、磁気光学結晶１及び偏光子２をその順で通過する。

【０００６】この光可変減衰器では、第１の磁界印加手段３で発生された磁界ベクトルと第２の磁界印加手段４で発生された磁界ベクトルとの合成ベクトル（合成磁界）が、磁気光学結晶１に加えられる。このとき、第１の磁界印加手段３で発生された磁界ベクトルが飽和磁界よりも大きいとき、合成ベクトルも飽和磁界よりも大きくなる。この場合、磁気光学結晶１は、実質的に内部の磁区が１つに統合された状態になり、磁気光学結晶１が多くの磁区を有する場合に発生する光ビーム５の損失は低減される。

【０００７】第２の磁界印加手段４の磁界の強さが印加電流によって調整されると、合成磁界の方向も印加電流に応じて変化する。合成磁界の光ビーム５と同じ方向の成分（磁化ベクトル）の強さに応じて、光ビーム５の偏光方向がファラデー効果によって回転させられる。このファラデー回転角θは、一般的に次式で表される。

【０００８】

$$\theta = V \cdot L \cdot H \tag{1}$$

Ｖは、ヴェルデ定数であり、磁気光学結晶１の材質によって決定される。Ｌは、磁気光学結晶１における光路長、Ｈは、磁界の強さを示す。磁気光学結晶１によって偏光方向が回転された光ビーム５は、偏光子２に進む。このとき、偏光子２における偏光方向と、光ビーム５の偏光方向が一致している場合、全ての光ビーム５は、偏光子２を通過する。両者の偏光方向が一致しない場合、光ビーム５の偏光子２の偏光方向の成分のみが通過する。両者の偏光方向が９０度の角度差を有するとき、光ビーム５は偏光子２を通過せず、減衰量が最大となる。

【０００９】また、特開平６－５１２５５「光アッテネータ」には、その他の光可変減衰器が示されている。図３０に、従来の光可変減衰器の第２の構成例を示す。本光可変減衰器は、光ファイバ６ａと、レンズ７ａと、ウェッジ状の複屈折結晶８ａと、図２９に示したファラデー回転子９と、ウェッジ状の複屈折結晶８ｂと、レンズ７ｂと、光ファイバ６ｂとで構成されている。本光可変減衰器では、光ファイバ６ａから供給された光ビームの複屈折結晶８ａ，８ｂによる複屈折を利用して、光ビームの一部が光ファイバ６ｂに導かれる。光ファイバ６ｂに導く量は、ファラデー回転子９における光ビームの偏光方向の回転角で調整できるので、光ビームのパワーを可変に減衰できる。

【００１０】本光可変減衰器は、図２９に示す光可変減衰器と異なり、光ファイバ６ａから供給される光ビームの偏光方向に係わらず動作可能である。上記に示した光可変減衰器は、機械的な可動部分を有しておらず、小型化が可能である。

【００１１】

【発明が解決しようとする課題】しかしながら、上述した磁気光学結晶を用いた従来の光可変減衰器には次のような問題点がある。図２９に示す従来の光可変減衰器の第１の構成例では、光可変減衰器に使用する磁気光学結晶（ファラデー素子）として、一般的にＹＩＧやファラデー効果を有するガーネット厚膜が良く用いられる。しかし、このようなファラデー素子は、一般的に回転角度に対する波長依存性や温度依存性を有する。表１に、ファラデー素子のファラデー回転角の波長依存性及び温度依存性を示す。

【００１２】

【表１】

項　目	ガーネット厚膜（一例）	ＹＩＧ
波長依存性	－0.083 deg/nm	－0.040 deg/nm
温度依存性	－0.086 deg/nm	－0.042 deg/℃

【００１３】表１は、１５５０ｎｍ帯におけるファラデー回転角が４５度のときの波長及び温度の変化に対するファラデー回転角の変化を示している。ガーネット厚膜は、その組成により特性が変化する。上記の例は、比較的大きい場合を示している。上記の表１は、波長或いは温度が増加したとき、ファラデー回転角が減少することを示している。

【００１４】また、図３１に、磁界Ｈとファラデー回転角との関係を示す。図３１では、磁界Ｈを増加すると、ファラデー回転角は傾きＶ×Ｌで増加し、所定の大きさ以上の磁界ではファラデー回転角は飽和する。これは磁気光学結晶の内部の磁区が単一磁区になったことを示す。図３１では、温度或いは波長が変化すると、傾きＶ×Ｌが変化する。これは、ヴェルデ定数に、波長依存性、温度依存性があることを示している。

【００１５】上述したように、従来の磁気光学結晶を用いた光可変減衰器には、減衰量の温度依存性や波長依存性が存在する問題があった。さらに、光可変減衰器を光伝送装置に組み込むためには、光可変減衰器の大きさをさらに小型化し、駆動電流を低減する必要がある。

【００１６】また、図３１に示す従来の光可変減衰器の第２の構成例では、僅かな偏光依存性による損失（Ｐｏｌａｒｉｚａｔｉｏｎ　Ｄｅｐｅｎｄｅｎｔ　Ｌｏｓｓ：ＰＤＬ）が、まだ生じている。本発明の目的は、上記の問題点を鑑みて、減衰量の温度依存性や波長依存性、及び駆動電流を低減し、光伝送装置に容易に適用可能な磁気光学結晶を用いた小型な光可変減衰器を提供する。

【００１７】本発明のその他の目的は、ウェッジ状複屈折結晶を用いた光可変減衰器における偏光依存性による損失を低減する。

【００１８】

【課題を解決するための手段】上記課題を解決するために本発明では、下記の手段を講じたことを特徴とするものである。請求項１記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光ビームをその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されていることを特徴とする。

【００１９】請求項２記載の発明装置では、請求項１記載の光可変減衰器において、前記光ビームを発生する偏光子をさらに有し、前記検光子の偏光方向は、前記偏光子の偏光方向と実質的に直交状態に設定されていることを特徴とする。

【００２０】請求項３記載の発明装置では、請求項１又は２記載の光可変減衰器において、前記検光子の偏光方向と、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向とは、８０度±３０度の角度で設定されていることを特徴とする。

【００２１】請求項４記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に印加するための磁界を電気的に発生する磁気回路と、前記磁気回路の内部及び近傍のどちらかに設けられ、前記磁気回路で電気的に発生する磁界と実質的に平行に前記磁気光学結晶に印加されるバイアス磁界を発生する永久磁石とを有し、前記磁気回路で電気的に発生する磁界が失われた場合でも、前記磁気光学結晶に磁界が印加され前記光ビームの少なくとも一部は透過されることを特徴とする。

【００２２】請求項５記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に印加するための磁界を電気的に発生する磁気回路と、前記磁気回路で電気的に発生する磁界と実質的に９０度より小さい角度で前記磁気光学結晶に印加されるバイアス磁界を発生する永久磁石とを有し、前記磁気回路で電気的に発生する磁界が失われた場合でも、前記磁気光学結晶に磁界が印加され前記光ビームの少なくとも一部は透過されることを特徴とする。

【００２３】請求項６記載の発明装置では、請求項４又は５記載の光可変減衰器において、前記磁気光学結晶を通過した光ビームをその偏光方向に応じて通過させる検光子をさらに有し、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されていることを特徴とする。

【００２４】請求項７記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に印加するための磁界を発生し、内部のギャップに前記磁気光学結晶が挿入されたヨークを有する磁気回路とを有し、前記磁気回路のヨークで発生された磁界が効率良く前記磁気光学結晶に印加されることを特徴とする。

【００２５】請求項８記載の発明装置では、請求項７記載の光可変減衰器において、前記磁気回路は、前記ヨークのギャップの近傍に設けられ前記ギャップに磁界を電気的に発生させるための少なくとも１つのコイルをさらに有することを特徴とする。

【００２６】請求項９記載の発明装置では、請求項７記

載の光可変減衰器において、前記光ビームを収束して前記磁気光学結晶に入射するための第１のレンズをさらに有し、前記第１のレンズによって収束された光ビームのサイズに応じて前記ヨークのギャップの間隔が狭くされ、該ギャップに発生する磁界を前記磁気光学結晶に効率よく印加することを特徴とする。

【００２７】請求項１０記載の発明装置では、請求項９記載の光可変減衰器において、前記収束された光ビームが前記磁気光学結晶を通過した後、前記収束された光ビームを所定の大きさに設定するための第２のレンズを含むことを特徴とする。

【００２８】請求項１１記載の発明装置では、所定の波長帯域を有する光信号を増幅する光増幅装置であって、波長依存性がある利得特性を有する光増幅器と、磁気光学結晶における光信号の偏光方向の回転を用いて該光信号を可変的に減衰し、減衰特性は前記光増幅器における利得の前記波長依存性と実質的に逆の波長依存性を有する光可変減衰器とを有し、前記光可変減衰器において、前記光信号が減衰されると共に、前記光増幅器における利得の前記波長依存性が低減されることを特徴とする。

【００２９】請求項１２記載の発明装置では、請求項１１記載の光増幅装置において、前記光可変減衰器は、前記光信号の偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光信号をその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向、前記光信号の偏光方向、及び前記磁気光学結晶は、所定の減衰量において、前記逆の波長依存性が実質的に得られるように設定されていることを特徴とする。

【００３０】請求項１３記載の発明装置では、光増幅器に接続され前記光増幅器における利得の波長依存性を低減しかつ光信号を減衰するための光可変減衰器であって、前記光信号の偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光信号をその偏光方向に応じて通過させる検光子とを有し、前記検光子の偏光方向、前記光信号の偏光方向、及び前記磁気光学結晶は、所定の減衰量において、前記光増幅器の利得の波長依存性と実質的に逆の波長依存性が得られるように設定されていることを特徴とする。

【００３１】請求項１４記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光ビームの少なくとも一部を前記光可変減衰器の出力に導く検光子と、前記光可変減衰器の出力光を一部分岐して出力パワーをモニタする出力側受光器とを有し、前記出力側受光器でモニタした前記光可変減衰器の出力パワーが所定の値になるように、前記磁気光学結晶における前記光ビームの偏光方向が制御されることを特徴とする。

【００３２】請求項１５記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶を通過した光ビームの少なくとも一部を前記光可変減衰器の出力に導く検光子と、前記磁気光学結晶に入力される光ビームの入力パワーをモニタする入力側受光器と、前記光可変減衰器の出力パワーをモニタする出力側受光器とを有し、前記入力側受光器でモニタした前記光ビームの入力パワーと前記出力側受光器でモニタした前記光可変減衰器の出力パワーとの比が所定の値になるように、前記磁気光学結晶における前記光ビームの偏光方向が制御されることを特徴とする。

【００３３】請求項１６記載の発明装置では、請求項１４又は１５記載の光可変減衰器において、前記検光子は複屈折結晶を含み、前記検光子おいて偏光を分離された光ビームの一部を前記出力側受光器に導くアパーチャをさらに有することを特徴とする。

【００３４】請求項１７記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に印加するための磁界を内部のギャップに発生する磁気回路と、前記磁気光学結晶及び前記磁気回路を収容し基板に実装するための筐体とを有し、前記磁気回路は、前記ギャップの方向が実質的に前記筐体の高さ方向であるように筐体に実装されることを特徴とする。

【００３５】請求項１８記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に近接して置かれ前記磁気光学結晶に印加するための磁界を発生する磁気回路であって、前先端部が他の部分より細くなっている馬蹄形形状のヨークを含み前記先端部が前記磁気光学結晶を挟むように近接している前記磁気回路とを有することを特徴とする。

【００３６】請求項１９記載の発明装置では、請求項１８記載の光可変減衰器において、前記磁気回路は永久磁石で構成され、また前記磁気光学結晶に近接して置かれ前記磁気光学結晶に印加するための磁界を電気的に発生する電磁石をさらに有し、前記永久磁石のヨークの先端部は、前記電磁石よりも前記磁気光学結晶により近接していることを特徴とする。

【００３７】請求項２０記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、少なくとも一部に半硬質磁性体を含むヨークを有し、前記磁気光学結晶に印加するための磁界を駆動電流によって電気的に発生する磁気回路とを有し、前記駆動電流の供給が停止しても前記磁界は維持されることを特徴とする。

【００３８】請求項２１記載の発明装置では、請求項２０記載の光可変減衰器において、前記ヨークは、飽和状態における磁化の異なる複数の半硬質磁性体を部分的に有し、前記半硬質磁性体毎に磁化を制御することによっ

て前記磁気回路で発生する磁界の大きさを段階的に変更できることを特徴とする。

【００３９】請求項２２記載の発明装置では、光ビームのパワーを減衰する光可変減衰器であって、前記光ビームを複屈折させる第１のウェッジ状複屈折結晶と、前記第１のウェッジ状複屈折結晶で偏光を分離された前記光ビームの偏光方向を可変に回転させる磁気光学結晶と、前記磁気光学結晶に前記光ビームと実質的に垂直に印加するための磁界を発生する磁気回路と、前記磁気光学結晶から出力される光ビームを複屈折させる第２のウェッジ状複屈折結晶とを有し、前記第１のウェッジ状複屈折結晶で偏光を分離された前記光ビームで構成される平面に実質的に垂直に、前記磁気回路の磁界が前記磁気光学結晶に印加されることを特徴とする。

【００４０】上記の発明装置は、以下のように作用する。請求項１乃至３のうちいずれか１項記載の光可変減衰器においては、前記検光子の偏光方向は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されている。

【００４１】この場合、ファラデー回転角が大きいと、波長の変化に対するファラデー回転角の変化量も大きい。しかし、ファラデー回転角の変化に対する減衰量の変化量は小さいので、波長の変化に対する減衰量の変化量を低減できる。また、ファラデー回転角が小さいと、波長の変化に対するファラデー回転角の変化量も小さい。従って、この場合、ファラデー回転角の変化に対する対する減衰量の変化量が大きいが、波長の変化に対する減衰量の変化量を低減できる。

【００４２】従って、本光可変減衰器では、減衰量の波長依存性を低減できる。また、同様に同様に減衰量の温度依存性も低減できる。請求項４乃至６のうちいずれか１項記載の光可変減衰器においては、永久磁石で発生された磁界或いはその一部が、磁気光学結晶に光ビームと平行に常に印加されている。従って、本光可変減衰器では、故障等で、磁気回路へ印加する電流が流れなくなっても、光ビームを透過することができる。その結果、伝送装置の動作に与える影響を低減できる。さらに、波長・温度依存性を低減することもできる。

【００４３】特に、請求項５記載の光可変減衰器では、より簡易な構成で、上述の効果を得ることができる。請求項７乃至１０のうちいずれか１項記載の光可変減衰器においては、磁気光学結晶（ファラデー素子）は、ヨークのギャップ中に隙間なく挿入できる。従って、ヨークで発生した磁界は、外部に洩れることなく効率良く磁気光学結晶に供給でき、その結果、磁気光学結晶に強い磁場を均一に印加することができる。よって、磁気光学結晶とヨークとの間に隙間がある構成に比べて、磁気回路に供給する電流を低減でき、磁気回路の駆動電力を低減できる。

【００４４】特に、請求項８記載の光可変減衰器では、コイルが磁気光学結晶の近傍に設けられていることによって、ヨーク中の磁気抵抗の影響が低減され、効率よくヨークで発生した磁界を磁気光学結晶に供給することができる。従って、電磁石の駆動電力をより低減できる。さらに、ヨークのループ側の高さを低くできるので、光可変減衰器の高さも低くでき、その結果、実装の容易性が向上する。

【００４５】また、請求項９又は１０記載の光可変減衰器では、ヨークのギャップの間隔を例えば、２００μｍ程度まで狭くすることができる。従って、ヨークで発生した磁界を効率よくファラデー素子に印加でき、駆動電力を一層低減することができる。

【００４６】請求項１１又は１２記載の光増幅装置、及び請求項１３記載の光可変減衰器においては、検光子の偏光方向、光信号の偏光方向、及び磁気光学結晶を調節することによって、減衰量の波長依存性を任意に設定できる。従って、利得等化用の光フィルタを使用しないで、光増幅器の利得の波長依存性を低減することができる。また、本光可変減衰器では、減衰量が大きいほど波長依存性が大きくできる。従って、光励起パワーの上限値が小さい場合の光増幅器の利得の波長依存性を良好にキャンセルできる。よって、光ファイバ増幅器の励起光のパワーを小さく設定することができ、光ファイバ増幅器の小型化、低消費電力化が可能になる。

【００４７】請求項１４乃至１６のうちいずれか１項記載の光可変減衰器においては、出力側受光器でモニタした光可変減衰器の出力パワーパワーが所定の値になるように制御されたり、入力側受光器でモニタした光ビームのパワーと出力側受光器でモニタした光可変減衰器の出力パワーとの比が所定の値になるように制御される。従って、光可変減衰器の減衰量の温度特性、経時劣化、偏波ロス変動等の補正が可能になる。

【００４８】請求項１７記載の光可変減衰器においては、磁気回路をリング状ヨークで構成すると、光ビームの上側と下側にそれぞれリング状ヨークの半径に相当するスペースを確保するだけでよい。従って、光可変減衰器の高さを低くすることができる。

【００４９】請求項１８又は１９記載の光可変減衰器においては、磁気回路の磁界を効率的に磁気光学結晶に印加できる。従って、磁気回路は、外部に磁場を漏洩することを防ぐことができ、他の磁石への影響も低減できる。請求項２０記載の光可変減衰器においては、ヨークは少なくとも一部に半硬質磁性体を含む。従って、パルス電流の印加でヨークが磁化され、電流の供給を停止してもその磁化は保持される。よって、光可変減衰器の消費電力を低減できる。

【００５０】請求項２１記載の光可変減衰器においては、磁化の異なる複数の半硬質磁性体を制御することによって、電磁石で発生する磁界を安定に段階的に設定することができる。請求項２２記載の光可変減衰器におい

ては、磁気光学結晶の磁区を単一化するためのバイアス磁界を屈折平面に実質的に垂直に印加される。それにより偏光依存性損失を低減することができる。

【００５１】

【発明の実施の形態】最初に、本発明の第１の原理について説明する。図１は、本発明に係わる光可変減衰器の構成例である。この光可変減衰器は、偏光子（Ｐ）１０、磁気光学結晶であるファラデー素子（ＦＲ）２０、及び検光子（ａｎａｌｙｚｅｒ）（Ａ）３０より構成される。光ビーム５は、偏光子１０、ファラデー素子２０、検光子３０の順に供給される。

【００５２】また、光可変減衰器はさらに、ファラデー素子２０に磁界を印加するための永久磁石４０と、ヨーク５２及びコイル５４からなる電磁石５０を有している。永久磁石４０による磁界は、ファラデー素子２０に、光ビーム５の方向と垂直の方向に印加され、電磁石５０による磁界は、ファラデー素子２０に、光ビーム５の方向と同じ方向に印加される。

【００５３】光ビーム５が偏光子１０に供給されると、偏光子１０の偏光方向と同じ偏光方向を有する直線偏光の光が出力される。この直線偏光の光は、ファラデー素子２０を通過し、このとき、通過光の偏光方向は、光ビーム５の方向に発生した磁化ベクトルの大きさに応じてファラデー効果によって回転される。偏光方向が回転された光ビーム５は、検光子３０へ供給される。

【００５４】永久磁石４０による磁界は、ファラデー素子２０内の磁区を単一にするくらいに十分大きい。従って、永久磁石４０と電磁石５０との合成磁界も十分大きく、従ってファラデー素子２０内での光ビーム５の損失は非常に少なくできる。電磁石５０の磁界の大きさは、コイル５４に印加する電流によって変化でき、それによって、合成磁界の方向も変化できる。このとき、合成磁界のうちの光ビーム５と同一の方向の成分（磁化ベクトル）によって、光ビーム５の偏光方向がファラデー効果によって回転させられる。ファラデー効果によって回転された光ビーム５の偏光方向が、検光子３０の偏光方向と一致しない場合、光ビーム５の一部或いは全部が検光子３０によって遮断され、光ビーム５は減衰する。

【００５５】以上の動作は、従来の磁気光学結晶を用いた光可変減衰器の動作と実質的に同じである。本発明では、さらに、偏光子１０及び検光子３０は、ファラデー素子２０におけるファラデー回転が無い状態（光軸方向の磁界が零）の光ビーム５の偏光方向が、検光子３０の偏光方向とほぼ直交状態になるように構成されている。これにより、光可変減衰器の減衰量の温度依存性及び波長依存性を低減することができる。また、上記の直交状態は、光路中に、波長板（偏光を回転できる）を挿入して、偏光子及び検光子の配置を調整することによっても設定可能である。例えば、偏光子と検光子は０度配置に設定しても、波長板を挿入し偏光を９０度回転させることによって、実質的に９０度配置を設定することができる。

【００５６】以下に原理及び動作について説明する。従来の光可変減衰器では、偏光子１０の偏光方向と検光子３０の偏光方向との角度差は、任意の値に設定できるが、ここでは説明を簡単にするため、３種類の角度差（配置）について検討する。図２に、偏光子（Ｐ）、ファラデー素子（ＦＲ）、検光子（Ａ）の配置例を示す。図２の（Ａ）は、０度配置と称し、偏光子の偏光方向と検光子の偏光方向が平行である場合、図２の（Ｂ）は、４５度配置と称し、偏光子の偏光方向と検光子の偏光方向との角度差が４５度の場合、図２の（Ｃ）は、９０度配置と称し、偏光子の偏光方向と検光子の偏光方向が直交している場合である。図２の（Ｃ）に示す配置が、本発明に係わる光可変減衰器に適用されている。

【００５７】光可変減衰器の減衰量Ａは、ファラデー素子により回転した光の偏光方向と検出子の偏光方向との相対角度をθとすると、以下の式で示される。

$$A = 10 \log(\cos^2(90-\theta+E)) + Lo \quad (2)$$

Ｅ：消光比（真数）、Ｌｏ：損失（ｄＢ）

ここで、Ｅは、光可変減衰器を構成する光学部品の消光比、Ｌｏは、光学部品の内部損失である。この式により、光可変減衰器の減衰量Ａは、$\cos^2\theta$に応じて増加する。図３に、０度配置の場合のファラデー回転角に対する減衰量の計算結果を示す。図４に、４５度配置の場合のファラデー回転角に対する減衰量の計算結果を示す。図５に、９０度配置の場合のファラデー回転角に対する減衰量の計算結果を示す。上記の図では、ファラデー回転角をＣｏｎｔｒｏｌ　Ａｎｇｌｅ（ｄｅｇ）と称している。

【００５８】（Ａ）の０度配置では、ファラデー回転角が０度（印加磁場が零）のとき、減衰量は最も小さく、ファラデー回転角を増加するに従って、減衰量が増大し、９０度のファラデー回転角において減衰量は最大となる。この場合、２０度付近までのファラデー回転角に対しては、減衰量の変化は緩やかであり、９０度付近のファラデー回転角では、回転角度に対する減衰量の変化は大きい。上記の制御を達成するためには、ファラデー素子の長さＬは、９０度以上回転できる長さが必要である。

【００５９】（Ｂ）の４５度配置では、ファラデー回転角が０度（印加磁場が零）のとき、減衰量は３ｄＢである。回転角を－４５度に設定すると、減衰量は最小となり、＋４５度に設定すると減衰量は最大となる。この場合、４５度付近のファラデー回転角では、回転角度に対する減衰量の変化が大きい。上記の制御において、逆向きの電流を印加することによって、逆方向のファラデー回転を得ることができる。従って、ファラデー素子の長さＬは、４５度以上回転できる長さでよい。よって、（Ａ）の場合のファラデー素子の長さの半分でよい。

【００６０】（Ｃ）の９０度配置では、ファラデー回転角が０度（印加磁場が零）のとき、減衰量は最も大きく、ファラデー回転角を増加するに従って、減衰量が減少し、９０度のファラデー回転角において減衰量は最小となる。この場合、０度付近のファラデー回転角に対しては、回転角に対する減衰量の変化は大きく、９０度付近のファラデー回転角では、回転角度に対する減衰量の変化は小さい。上記の制御を達成するためには、ファラデー素子の長さＬは、９０度以上回転できる長さが必要である。

【００６１】以上の説明に示した様に、最大減衰量付近では、僅かなファラデー回転角の変化で急激な減衰量の変化が生じる。しかし、検討の結果、波長或いは温度の変化に対するファラデー回転角の変化量は、ファラデー回転角に依存することがわかった。図６は、ファラデー回転角と波長或いは温度の変化に対するファラデー回転角の変化量との模式的な関係図である。ファラデー回転角の変化量は、ファラデー回転角に比例している。即ち、ファラデー回転角が０度の場合（印加磁界が零）、波長或いは温度の変化によるファラデー回転角の変化量は、零であり、ファラデー回転角が増加するに従ってファラデー回転角の変化量も増える。

【００６２】従って、ファラデー回転が発生しない状態（２つの磁石の合成磁界の光ビームと平行の成分が実質的に零となる状態）のときに、波長或いは温度の変化に＊＊よるファラデー回転角の変化量は最小（実質的に零）であり、この状態で、最大減衰量が得られる様に偏光子、検光子を配置すれば、ファラデー回転角の変化に対する減衰量の変化も小さくなる。従って、減衰量の温度依存性や波長依存性を軽減することができる。このような配置は、上記の（Ｃ）の９０度配置に相当する。

【００６３】すなわち、波長或いは温度の変化によるファラデー回転角の変化量が最小となるファラデー回転角が零度のときに、ファラデー回転角に対する減衰量の変化量の大きい最大減衰量が得られるようにし、ファラデー回転角の変化量が大きくなる大きいファラデー回転角のときに、緩やかな減衰量の変化を示す小さい減衰量が得られるようにする。

【００６４】具体的には、ファラデー回転角が０度の場合、最大減衰が得られる様に偏光子の偏光方向、検光子の偏光方向の配置を９０度に設定する。この場合、ファラデー回転角が９０度となる最大透過時には、温度或いは波長の変化によってファラデー回転角が大きく変化するが、最大透過時は、ファラデー回転角の変化に対して減衰量の変化が非常に緩やかであるため、減衰量の変動は非常に小さくできる。

【００６５】表２に、偏光子及び検光子の０度配置、４５度配置、９０度配置の場合の特徴を示す。

【００６６】

【表２】

Ｐ．Ａ配置	電流零時の減衰量	電流と減衰量の関係	駆動電流方向	駆動電流値比率	ＦＲ素子の厚さ比率	波長・温度依存性	入出力ポートの区別
０度	最小減衰	流すと減衰	単極性	1	1	大	なし 同一動作
４５度	1/2 減衰	極性に依存	両極性	±1/2	１／２	中	あり 相補動作
９０度	最大減衰	流すと透過	単極性	－１	1	小	なし 同一動作

【００６７】０度配置及び９０度配置の場合、入出力ポートの区別は無い。どちらから入力しても、同様の減衰特性を得ることができる。これに対して、４５度配置の場合は、入出力ポートを入れ換えると非相反的な動作を行う。電流が０の場合は、どちらから入力しても３ｄＢの減衰となるが、一方から無減衰で光ビームを透過させている場合は、反対方向からは最大減衰となる。即ち、アイソレータとして動作する。

【００６８】また、図７から図１１に、偏光子と検光子の偏光方向の角度差がそれぞれ０度、４５度、７０度、８０度、９０度の場合の、波長に対する減衰特性を示す。各図の（Ａ）は、波長に対する任意の減衰量の変化を示し、各図の（Ｂ）は、波長に対する任意の減衰量の偏差を示している。（Ｂ）では、偏差は、波長１５４５ｎｍで正規化されている。

【００６９】図７の０度配置では、２０ｄＢ以上の減衰量を得る場合、波長に対する減衰量の偏差が大きい。これに対して、図１１の９０度配置では、３５ｄＢ以上の減衰量に対しても、波長に対する減衰量の偏差は非常に小さい。また、減衰量が１ｄＢの場合、ファラデー回転角は大きく、例えば、±１５ｎｍの波長変動に対して、ファラデー回転角の変化は、約±２．５度となる。しかし、図１１の（Ｂ）で示されるように、その時の減衰量の偏差は±０．０１ｄＢ以下であり、光伝送の動作に影響は与えない。

【００７０】光可変減衰器を光伝送装置に適用する場合、一般的に、０～２０ｄＢの減衰量がよく使用される。従って、０～２０ｄＢの減衰量に対する偏差を計算

すると、図１０に示す８０度配置の場合の偏差が最も小さいことが分かった。さらに、一般的な使用条件を考慮すると、検光子、偏光子の偏光方向の角度差は、８０度±３０度程度の範囲内に配置すれば、実用上十分に波長依存性を低減することができる。

【００７１】従って、図１における本発明の光可変減衰器では、偏光子及び検光子は、ファラデー素子２０におけるファラデー回転が無い状態の光ビーム５の偏光方向が、検光子の偏光方向とほぼ直交状態になるように構成される。さらに、偏光子及び検光子の偏光方向の角度差は、８０度±３０度であることが望ましい。

【００７２】本発明は、図１に示す構成例の他に、光可変減衰器の他の構成例にも適用可能である。図１２は、本発明に係わる光可変減衰器の他の構成例である。この光可変減衰器は、図１の光可変減衰器と同様に、偏光子１０、ファラデー素子２０、及び検光子３０より構成される。さらに、偏光子１０及び検光子３０は、それぞれの偏光方向がほぼ直交状態になるように配置されている。ここでは、説明を簡単にするため、偏光方向の差は９０度とする。

【００７３】図１２に示す光可変減衰器は、さらに、ファラデー素子２０に磁界を印加するための永久磁石４２と、ヨーク５７及びコイル５９からなる電磁石５５を有している。永久磁石４２は、ドーナツ状の穴を有する２つの磁石で構成されており、光ビーム５は、穴を通過する。永久磁石４２による磁界は、ファラデー素子２０に、光ビーム５の方向と平行の方向に印加され、電磁石５５による磁界は、ファラデー素子２０に、光ビーム５の方向と垂直の方向に印加される。

【００７４】偏光子１０から出力された直線偏光を有する光ビーム５は、永久磁石４２の穴を介してファラデー素子２０を通過する。偏光方向がファラデー回転された光ビーム５は、さらに他の永久磁石４２の穴を介して検光子３０へ供給される。永久磁石４２による磁界は、ファラデー素子２０内の磁区を単一にするくらいに十分大きい。従って、永久磁石４２と電磁石５５との合成磁界も十分大きく、従ってファラデー素子２０内での光ビーム５の損失は非常に少なくできる。

【００７５】この光可変減衰器では、コイル５９へ印加する電流を零にすると、光ビーム５の方向のみに永久磁石４２の磁界がかかる。このとき、光ビーム５の偏光方向は大きくファラデー回転し、ファラデー回転角が９０度の場合、減衰量は最小となる。一方、コイル５９へ印加する電流を増大すると、光ビーム５の方向の磁化ベクトルは減少し、ファラデー回転角も減少する。ファラデー回転角が実質的に０度のとき（永久磁石４２と電磁石５５との合成磁界の方向が、光ビーム５の方向と実質的に垂直になった場合）、減衰量は最大となる。ファラデー回転角と減衰量との関係は、図５に示す関係と同じである。

【００７６】ファラデー回転角が大きいと、波長の変化に対するファラデー回転角の変化量も大きい。しかし、この場合、図５に示すように、ファラデー回転角の変化に対する減衰量の変化量は小さい。よって、波長の変化に対する減衰量の変化量を低減できる。

【００７７】また、ファラデー回転角が小さいと、波長の変化に対するファラデー回転角の変化量も小さい。従って、この場合、ファラデー回転角の変化に対する対する減衰量の変化量が大きいが、波長の変化に対する減衰量の変化量を低減できる。本光可変減衰器では、温度変化に対しても、同様に減衰量の変化量を低減できる。また、この光可変減衰器を光伝送装置に適用する場合、図１に示す光可変減衰器と同様に、偏光子と検光子の偏光方向の角度差は、８０度±３０度が好ましい。

【００７８】なお、本発明に係わる光可変減衰器における偏光子及び検光子の偏光方向の配置は、磁気回路の配置に係わらず、種々の磁気回路の構成に適用可能である。次に、本発明に係わる光可変減衰器の第２の原理について説明する。本発明に係わる光可変減衰器では、電磁石に印加する電流が零のときに、常に光可変減衰器は透過状態にされる。

【００７９】上述した偏光子と検光子の９０度配置は、波長依存性、温度依存性を非常に小さくできるが、図１に示す光可変減衰器の磁気回路（永久磁石４０及び電磁石５０）の構成の場合、電磁石５０のコイル５４に印加する電流（駆動電流）が零のとき、減衰量は最大となる。制御回路の故障等で駆動電流が切れた場合に自動的に減衰量が最大となり、これはフェールセイフ機能となる。しかし、逆に光が透過しないため、装置アセンブリに影響を与える恐れがある。実用的には、後者の欠点の方が多い。

【００８０】図１３は、本発明に係わる光可変減衰器の第２の原理を説明するための図である。図１３に示す光可変減衰器は、図１に示す光可変減衰器と比べて、電磁石５０の代わりに電磁石６０が設けられている。電磁石６０は、永久磁石６６を内蔵するヨーク６２とコイル６４とで構成されている。また、説明の都合上、永久磁石４０は、省略されている。その他の構成は、図１の光可変減衰器と同じである。従って、偏光子１０及び検光子３０は、それらの偏光方向の角度差が９０度であるように設置されている。図１の光可変減衰器と同じ機能を有する要素には同じ参照番号が付されている。

【００８１】図１３の光可変減衰器では、電磁石６０内の永久磁石６６によって、光ビーム５の方向にバイアス磁界が印加される。このバイアス磁界の強さは、ファラデー素子２０におけるファラデー回転角が９０度であるように設定されている。さらに、コイル６４に電流を印加したときに発生する電磁石６０の磁界は、永久磁石６６のバイアス磁界を打ち消すように動作する。

【００８２】この光可変減衰器において、コイル６４へ

印加される電流が零のとき、永久磁石６６によって、光ビーム５の方向にバイアス磁界のみが印加され、光ビーム５の偏光方向はファラデー素子２０において９０度回転させられる。よって、回転された光ビーム５の偏光方向は、検光子３０の偏光方向と一致し、光可変減衰器の透過率は最大となる。一方、コイル６４へ印加される電流が増加すると、バイアス磁界は打ち消され、ファラデー回転は減少し、その結果、減衰量が増加する。

【００８３】従って、本光可変減衰器では、故障等で、電磁石６０へ印加する電流が流れなくなっても、光ビームを透過することができ、かつ波長・温度依存性を低減することもできる。図１４に、図１３に示す光可変減衰器の変更例を示す。図１４に示す光可変減衰器では、図１３に示す光可変減衰器と比べて、ファラデー素子２０の代わりに、その半分の長さを有するファラデー素子２２が設けられている。ファラデー素子２２の長さは、電磁石６０内の永久磁石６６のバイアス磁界によって、－４５度のファラデー回転が行なわれるように選択されている。その他の構成は、図１３の光可変減衰器と同じである。従って、偏光子１０及び検光子３０は、それらの偏光方向の角度差が９０度であるように設置されている。図１３の光可変減衰器と同じ機能を有する要素には同じ参照番号が付されている。

【００８４】この光可変減衰器では、電磁石６０に印加される電流が零のとき、永久磁石６６によるバイアス磁界のみファラデー素子２２に印加され、－４５度のファラデー回転が行なわれる。このとき、透過率は約５０％である。正方向に電流が電磁石６０に印加されると、バイアス磁界は、電磁石６０による磁界によって減少し、ファラデー回転角も減少する。ファラデー回転角が０度のとき、減衰量は最大となる。

【００８５】一方、負方向に電流が電磁石６０に印加されると、バイアス磁界に、電磁石６０による磁界が加わり、ファラデー回転角は負方向に増加する。ファラデー回転角が－９０度になったとき、透過率は最大となる。従って、本光可変減衰器においても、故障等で、電磁石６０へ印加する電流が流れなくなっても、光ビームを約５０％透過することができ、かつ波長・温度依存性を低減することもできる。さらに、ファラデー回転角が４５度に小さくできるので、電磁石に供給する電力を低減でき、光可変減衰器の低消費電力化も達成できる。

【００８６】上記の図１３及び図１４の光可変減衰器では、永久磁石をヨーク中に埋め込む構造を図示している。しかし、ヨークの材料の透磁率は非常に高いため、永久磁石をヨークに近接させるだけで、同様の効果を得ることができる。図１５に、図１４に示す光可変減衰器の変更例を示す。図１５に示す光可変減衰器では、図１４に示す光可変減衰器と比べて、電磁石６０の代わりに永久磁石を含まない電磁石５０が設けられ、さらに、ファラデー素子２２に斜めの方向からバイアス磁界を加えるための永久磁石７０が設けられている。その他の構成は、図１４の光可変減衰器と同じである。図１４の光可変減衰器と同じ機能を有する要素には同じ参照番号が付されている。

【００８７】前述の図１４の光可変減衰器では、ヨーク６２内に設けられた永久磁石６６によってバイアス磁界が、光ビーム５と平行に加えられている。この場合、ファラデー素子２２内の磁区を単一にするために、図１の光可変減衰器と同じように、別の永久磁石によって、光ビーム５と垂直の方向にバイアス磁界をさらに加えることができる。このとき、ファラデー素子２２には、これらのバイアス磁界がベクトル合成された合成磁界が加えられる。図１５に示す光可変減衰器では、この合成磁界を、１つの永久磁石７０によって形成することができる。

【００８８】従って、本光可変減衰器は、より簡易な構成で、図１４に示す光可変減衰器と同じ効果を有することができる。また、本発明は、図１４に示す光可変減衰器だけでなく図１３の光可変減衰器を含む他の構成例にも適用可能である。次に、本発明に係わる光可変減衰器の第３の原理について説明する。光可変減衰器を装置に組み込む場合、装置の低消費電力化を図るため、光可変減衰器の減衰量を制御する磁気回路のコイルに印加する駆動電力を低減する必要がある。そのためには、磁気回路で発生した磁場を効率よくファラデー素子に印加する必要がある。

【００８９】図１６は、本発明に係わる光可変減衰器の磁気回路の構成例である。図１６では、ヨーク８２及びコイル８４で構成される電磁石８０と、ファラデー素子２０とが示されている。ファラデー素子２０は、ヨーク８２のギャップ中に隙間なく挿入されている。従って、ヨーク８２で発生した磁界は、外部に洩れることなく効率良くファラデー素子２０に供給でき、その結果、ファラデー素子に強い磁場を均一に印加することができる。従って、ファラデー素子とヨークとの間に隙間がある構成に比べて、コイルに供給する電流を低減でき、電磁石の駆動電力を低減できる。

【００９０】図１７は、図１６に示した光可変減衰器の磁気回路の変更例である。（Ａ）は、上から見た断面図、（Ｂ）は、横から見た断面図を示す。図１７の光可変減衰器の磁気回路では、図１６に示す電磁石８０と比べて、コイル８４の代わりに、分割された２つのコイル８６－１、８６－２が、ファラデー素子２０の近傍に設けられている。

【００９１】コイルがファラデー素子２０の近傍に設けられていることによって、ヨーク中の磁気抵抗の影響が低減され、効率よくヨークで発生した磁界をファラデー素子２０に供給することができる。この構成によっても、電磁石の駆動電力を低減できる。さらに、ヨーク８２のループ側の高さを低くできるので、光可変減衰器の

高さも低くでき、その結果、実装の容易性が向上する。

【００９２】なお、図１７に示す光可変減衰器では、偏光子、検光子としてウェッジ状複屈折結晶を使用しており、これにより偏光依存性が除去できる。この動作は、特開平６－５１２５５「光アッテネータ」に開示されている。ヨークで発生した磁界を効率よくファラデー素子に印加する方法として、以下の方法も考えられる。図１６及び図１７の磁気回路において、ファラデー素子を挿入するヨークのギャップは狭いほど、効率良く磁場をファラデー素子に印加することができる。ファラデー素子の比透磁率はヨークのそれに比べて大きくないため、ファラデー素子を介して空間中に漏洩磁場が発生する恐れがある。

【００９３】このため、ヨークのギャップを出来るだけ狭く保つ必要がある。ギャップを狭くすると、光ビームが透過する面積が減少するため、コリメートされた光ビーム系を小さくする必要がある。この要求は、レンズの焦点距離を短くすることで実現可能である。例えば、レンズの焦点距離を０．７ｍｍにすると、コリメートされたビーム直径は約１４０μｍ程度に小さくできる。このため、組立トレランスを考慮してもヨークのギャップをその約２倍の３００μｍ程度以下に設定することは比較的容易である。

【００９４】図１８は、本発明の光可変減衰器のその他の構成例である。説明を簡単化するため、磁気回路は省略されている。図１８に示す光可変減衰器では、入射側のレンズにより光ビームがファラデー素子において収束される。従って、ファラデー素子において、ヨークのギャップをさらに狭くすることができる。光ビームは、１００μｍ程度まで絞ることができる。この光学系を光可変減衰器に適用すると、ヨークのギャップの間隔を２００μｍ程度まで狭くすることができる。よって、ヨークで発生した磁界を効率よくファラデー素子に印加でき、駆動電力を一層低減することができる。

【００９５】次に、本発明に係わる光可変減衰器の第４の原理について説明する。本発明に係わる光可変減衰器では、減衰量の波長依存性を利用することによって、光ファイバ増幅器の利得の波長依存性を補償することができる。まず、光ファイバ増幅器の問題点について説明する。光ファイバ増幅器は、Ｅｒ（エルビウム）添加光ファイバ増幅器（Ｅｒｂｉｕｍ－ＤｏｐｅｄＦｉｂｅｒＡｍｐｌｉｆｉｅｒ：ＥＤＦＡ）が良く使用されている。このＥＤＦＡは、外部から励起（ポンピング）光を供給することによって、入力光を増幅する構成を有している。

【００９６】図１９に、典型的なＥＤＦＡの増幅特性を示す。図１９は、１５５０ｎｍ付近において、４つの光信号が多重化された多重化信号が増幅されている場合を示している。この図から理解される様に、ＥＤＦＡは、１５３５ｎｍ近辺に利得のピークを有し、増幅特性は平坦ではない。従って、通常は、比較的利得が平坦な、１５４０－１５６０ｎｍ付近の波長帯域が光信号として利用されている。

【００９７】しかし、この波長帯域においても、光ファイバ増幅器の動作状態により、波長依存性が増大する恐れがある。図１９に示すように、出力パワーを一定制御している状態で入力パワーを増大したり、もしくは、入力パワーを一定にして出力パワーを増大すると（図１９のグラフでは、下側のグラフに相当）、１５６０ｎｍ側よりも１５４０ｎｍ側の短波長側の利得が低下する。

【００９８】光通信システムでは、光ファイバの長さが敷設する場所毎に異なるため、光ファイバ増幅器に入力されるパワーが異なる。従って、入力パワーが敷設場所ごとに異なる場合、出力パワーの利得の波長依存性が発生する。この波長依存性を防ぐためには、光ファイバ増幅器の利得を一定に保つ必要がある。利得が一定に制御されると、ＥＤＦＡ内のＥｒイオンの反転分布状態のイオンの割合が一定になり、波長依存性の変化を低減することができる。この場合、さらに以下の２つの問題が生じる。

【００９９】第１の問題は、常に光ファイバ増幅器における利得が一定に制御されると、入力パワーに応じて出力パワーが変化する。この場合、光ファイバでは、非常に小さい部分に光を閉じ込めて光の長距離伝搬が行なわれるため、非線形光学効果の影響が増大する。従って、非線形光学効果の影響をさけるため、光ファイバへの入力パワーを低減するように制御する必要がある。このため、従来の第１の方法では、図２０の様に、光出力を一定に保つために光可変減衰器が光ファイバ増幅器に接続され、さらに、波長依存性の変化を低減するために、光ファイバ増幅器の利得が一定に制御されている。この場合、利得の波長依存性を軽減させるためには、十分な励起光パワーを入力させる必要があり、消費電力の増大、装置の大型化等の問題がある。

【０１００】第２の問題は、光ファイバ増幅器の利得を一定に制御し、利得の波長依存性を低減する場合、励起パワーを大きくする必要があることである。反転分布状態を所定の状態に設定すると、１５４０ｎｍ－１５６０ｎｍの波長域の利得をほぼ平坦にすることができる。しかし、そのためには、励起パワーを大きくする必要がある。もし、励起パワーが低いと、前述したように反転分布が不完全な状態になり、長波長側の利得が持ち上がる。そこで、従来の第２の方法では、長波長側の損失が大きい特性を有する光フィルタが挿入され、少ない励起パワーで利得の波長依存性を低減できる。しかし、この方法では、光フィルタを必要とし、装置の構成が複雑になる。

【０１０１】以上の問題点を解決するため、前述した本発明に係わる光可変減衰器を適用できる。具体的には、図２０に示した構成における光可変減衰器ＡＴＴとし

て、本発明に係わる光可変減衰器を適用できる。この場合、光ファイバ増幅器の波長依存性（出力パワーが大きい場合の波長依存性：図１９の下側のグラフ）と逆の波長依存性を有するように、光可変減衰器の偏光子、検光子の角度配置、ＦＲ素子長等のパラメータが調整される。このような光可変減衰器の減衰特性を図２１に示す。長波長側において、減衰量が増加している。

【０１０２】本光可変減衰器を伝送装置に適用することによって、波長依存性をキャンセルするための光フィルタを除去できる。また、本光可変減衰器では、減衰量が大きいほど波長依存性が大きいため、光ファイバ増幅器の利得の波長依存性を良好にキャンセルできる。

【０１０３】後者の利点について、さらに詳細に説明する。もし、入力パワーに関わらず利得を一定に制御できる理想的な光ファイバ増幅器が存在すれば、後者の利点は不要であろう。しかし、実際の光ファイバ増幅器の励起光パワーは有限である。入力パワーが増大した場合、利得を一定に制御するために、励起光パワーを上げる必要がある。この時、光出力を一定に保つため、光可変減衰器の減衰量が増大される。

【０１０４】しかし、入力パワーがさらに増大して励起光パワーが上限値に到達すると、反転分布状態を一定に保つことが不可能になり、光ファイバ増幅器の長波長側の利得が増大する。励起光パワーの上限値が小さいと、その傾向はさらに大きくなる。従って、光可変減衰器が、減衰量が大きい程波長依存性が大きくなるという特性を有していると、励起光パワーの上限値が小さくても利得の波長依存性を効果的にキャンセルすることができる。よって、光ファイバ増幅器の励起光のパワーを小さく設定することができ、光ファイバ増幅器の小型化、低消費電力化が可能になる。

【０１０５】なお、この様な大きな波長依存性を有する光可変減衰器では、減衰量の温度依存性も大きい予想される。従って、この場合、ファラデー素子の温度を一定に保つ制御回路が付加されていることが望ましい。次に、本発明に係わる光可変減衰器の第５の原理について説明する。磁気光学効果を利用した光可変減衰器では、同一の減衰量に制御する際、減衰量を増加させる制御の場合と、減衰量を減少させる制御の場合とで、電磁石へ印加する駆動電流が異なる場合がある。これは、ファラデー素子の回転角度や磁気回路のヒステリシス特性に起因する。

【０１０６】図２２は、本発明に係わる光可変減衰器の第５の原理を説明するための構成例である。本構成では、光可変減衰器への入力パワー変動を抑圧し、出力パワーを一定に保つように制御できる。図２２に示す構成例では、図３０に示す光可変減衰器が使用されている。この光可変減衰器では、偏光子及び検光子として、減衰量の偏光依存性を低減するために、ルチル（ｒｕｔｉｌ：二酸化チタンTiO_2）や方解石等の複屈折を有する光学材料をウェッジ状に加工したものを使用している。入出力にファイバを設けずに空間ビームを減衰する場合や、偏波保持ファイバを入出力ファイバとして使用する場合、直線偏光が光可変減衰器に入力される。この場合、偏光子、検光子として、通常のプリズムや誘電体多層膜を使用した偏光分離器を使用することができる。また、図２２では、説明を簡単化するため、バイアス磁場を与える永久磁石は省略されている。

【０１０７】図２２の光可変減衰器では、光可変減衰器の出力側に、複屈折した２つの光ビームの一部を分岐する光カプラ１００と、レンズ１０２と、複屈折した２つの光ビームの一方を通すアパーチャ１０４と、アパーチャ１０４を通過した光パワーをモニタする受光器１０６が設けられ、光パワーが所定の値になるように光可変減衰器の減衰量が制御される。出力側の検光子８ｂ（複屈折結晶）を通過した光ビームは、光カプラ１００により、光ビームの一部を分離する。分離された光ビームは、レンズ１０２及びアパーチャ１０４を介して受光器１０６に入力される。

【０１０８】光カプラ１００の分岐比は、ファイバ６ｂに供給される主信号の減衰量が僅かであり、かつ分岐された光ビームが受光器１０６で十分モニタできるように設定される。例えば、分岐比は、１０：１～２０：１程度に設定できる。図２２の光可変減衰器では、光カプラで分離した光ビームがレンズ１０２及びアパーチャ１０４を介して受光器１０６に入力される。複屈折テーパ板を偏光子、検光子として使用した光可変減衰器では、ファラデー回転子９において光ビームの偏光方向が回転し、光ビームの出力光ファイバ６ｂでの結合位置にずれが生じる。従って、光ビームの一部は光ファイバ６ｂに供給されず、減衰動作が行なわれる。

【０１０９】減衰量が零の場合、出力ファイバ６ｂのコアの中央に光ビームが結合される。減衰を生じさせるために光ビームの偏光方向にファラデー回転が与えられると、コアからはずれた位置に光ビームが結合し、光パワーが減衰される。従って、分離された光ビームを受光器１０６で受信する場合においても、光ファイバと同様に受光面積を十分に小さく絞らないと、全ての光ビームが受光器１０６に供給され、光ビームのパワーを正確に測定できない。即ち、結合する位置を変化させても受光径がその位置ずれより広ければ、減衰量を測定できない。なお、モニタ側のレンズの焦点距離等を適当に設定すれば、光ファイバのコアよりも大きな面積の受光面を確保できる。従って、受光器１０６の前面に、アパーチャ１０４が設けられている。受光面が十分小さい場合は、アパーチャは不要である。

【０１１０】次に、図２２の光可変減衰器の外部に設けられた制御回路の動作について説明する。受光器１０６で光電変換した電気信号は、増幅器１０８により適当なレベルの電気信号に増幅される。増幅された電気信号

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は、誤差検出回路１１０に入力される。制御電圧発生回路１１２は、所望の光パワーに対応する電圧を出力する。リニアライザ１１４は、光可変減衰器のコイルへの印加電力と減衰量との関係を補正するために設けられている。ファラデー回転角は印加電力に対して比例するが、減衰量は、ファラデー回転角のｃｏｓ^2 に比例する。従って、設定電圧と出力光パワーとの関係を線形或いは対数の関係になるように、設定電圧が補正される。この設定電圧は、前述の電気信号と共に誤差検出回路１１０に入力され、それらの差分の信号が制御すべき誤差信号として出力される。

【０１１１】誤差検出回路１１０から出力された誤差信号では、位相補償回路１１６により電気回路の時定数の調整が行なわれる。ファラデー回転を生じさせる電磁石のコイルはインダクタンスを有しているため、応答特性が劣化しリンギングを発生する恐れがある。従って、位相補償回路１１６では、それらを防止するために制御回路の周波数特性が調整される。駆動回路１１８は、コイルを駆動するための電力増幅回路である。

【０１１２】上述した制御を使用することによって、制御電圧発生回路１１２で発生した設定電圧に相当する出力パワーを常に得ることができる。なお、制御電圧発生回路１１２は、外部からの制御電圧を与えることでリモート制御が可能となる。本構成例では、光可変減衰器の温度特性、経時劣化、偏波ロス変動等の補正も可能になる。

【０１１３】図２３は、図２２に示す光可変減衰器の変更例である。本光可変減衰器では、図２２に示す光可変減衰器と比べて、光ビームの分岐手段と受光手段とが光可変減衰器の入力側にさらに付加されている。この構成例では、入力光パワーに関係なく、所定の減衰量を得るように制御することができる。図２２と同じ機能を有するエレメントには同じ参照番号を付している。

【０１１４】本光可変減衰器では、入力側に出力側と同様に、光カプラ１００ａと受光器１０６ａとが設けられている。入力光パワーの一部（例えば、１／１０～１／２０）が分岐され、受光器１０６ａでモニタされる。入力側は、複屈折テーパ板からなる偏光子を通過する前に光パワーの一部が分岐されているため、出力側に設けられている受光径を制限するためのアパーチャ１０４は不要である。

【０１１５】図２３の光可変減衰器では、入力側及び出力側の受光器１０６ａ，１０６ｂで受光した信号は、増幅器１０８ａ，１０８ｂで適切なレベルまで増幅され、割算回路１２０に入力される。この割算回路１２０では、出力パワーと入力パワーの比が計算される。この演算結果は、誤差検出回路１１０に入力される。それと同時に、減衰量に対応する設定電圧も誤差検出回路１１０に入力される。誤差検出回路１１０は制御誤差信号を発生し、その信号は位相補償され、駆動回路１１８を介してコイルを駆動する。上記の制御回路によって、入力部と出力部の光パワーの比が一定になるように制御され、光可変減衰器の減衰量が一定に制御できる。

【０１１６】次に、本発明に係わる光可変減衰器の第６の原理について説明する。光可変減衰器を光伝送装置に実装する場合、光可変減衰器は小型化する必要がある。特に、プリント板上に実装し、そのプリント板を重ねて伝送装置を構成する場合があるので、光可変減衰器の高さを低くする必要がある。さらに、光伝送装置の消費電力の低減のために、光可変減衰器の消費電力を低減することは重要である。

【０１１７】図２４は、本発明に係わる光可変減衰器の第６の原理を説明するための構成例である。（Ａ）は、外観図、（Ｂ）は、ａ方向に見た図、（Ｃ）は、ｂ方向に見た図である。ただし、図２４では、説明を簡単にするため、ファラデー回転子のみ記載しており、偏光子、検光子は省略されている。

【０１１８】図２４に示すファラデー回転子は、ファラデー素子１３０と、ヨーク１３４及びコイル１３６を有する電磁石１３２と、永久磁石１３８とで構成される。電磁石１３２のヨーク１３４と永久磁石１３８は、ギャップを有するリング形状（例えば、馬蹄形）を成している。ファラデー素子１３０は、ヨーク１３４のギャップの中に設けられている。電磁石１３２は、ファラデー素子１３０に、光ビーム１４０と垂直の方向に磁界を印加し、永久磁石１３８は、ファラデー素子１３０に、光ビーム１４０の方向に磁界を印加している。

【０１１９】図２４の（Ｃ）では、特に、光可変減衰器が筐体１４２に収納されている様子を示している。この図では、電磁石１３２のギャップの方向が、筐体１４２の高さ方向に配置されている。従って、光ビーム１４０が、筐体１４２の高さのほぼ中間に位置することができる。

【０１２０】前述したように、実装上の理由により光デバイスの高さは低いことが望ましい。光可変減衰器の場合、電磁石のヨークがリング状の形をしているので、この直径が光可変減衰器の高さに大きく影響する。具体的には、光ビームの位置が光可変減衰器の高さの中間に設定されることが、外部とのインタフェース上望ましい。図２９に示す従来の光可変減衰器では、光ビームの上側と下側にそれぞれリング状ヨークの直径に相当するスペースが必要であり、光可変減衰器の高さが大きくなる。しかし、図２４に示す光可変減衰器の構成例では、光ビーム１４０の上側と下側にそれぞれリング状ヨークの半径に相当するスペースを確保するだけでよい。従って、光可変減衰器の高さを低くすることができる。

【０１２１】図２４の（Ｂ）では、永久磁石１３８が馬蹄形の形状を有し、光ビーム１４０を遮らない範囲で、ファラデー素子１３０にそれを挟むように近接設置されている。また、永久磁石１３８のヨークの先は細くなっ

ていることが示されている。上記の構成によって、図２９に示す従来の光可変減衰器と比べて、永久磁石１３８の磁界を効率的にファラデー素子１３０に印加できる。従って、永久磁石１３８は、外部に磁場を漏洩することを防ぐことができ、電磁石への影響も低減できる。これにより、電磁石の制御が複雑になるのを防ぐことができる。さらに、この場合、永久磁石１３８の磁力を低減できる。

【０１２２】さらに、図２４の（Ａ）に示すように、電磁石１３２のヨーク１３４は、ギャップに近い部分に半硬質磁性体１４４を含んでいる。図２９に示す従来の光可変減衰器では、ヨークが全て軟質磁性体で形成されているので、磁界を供給するために電磁石に常に電流を供給する必要がある。図２４に示すように電磁石のヨークに半硬質磁性体を使用すると、パルス電流の印加でヨークが磁化され、電流の供給を停止してもその磁化は保持される。従って、光可変減衰器の消費電力を低減できる。この場合、ヨーク全体を半硬質磁性体で構成する必要はなく、図２４（Ａ）に示すようにヨーク中に部分的に半硬質磁性体を設けることによってもその効果は得られる。

【０１２３】しかし、半硬質磁性体は、飽和領域では安定した磁化が得られるが、未飽和領域では大きなヒステリシス特性を示し、安定な磁化を得ることは難しい。従って、磁界の中間段階での制御は難しい。この問題を解決するために、図２５に示す構成が考えられる。図２５は、本発明に係わる光可変減衰器に使用する電磁石の構成を示す図である。

【０１２４】本電磁石では、電磁石のヨーク中に部分的にそれぞれの飽和領域での磁力が異なる複数の半硬質磁性体１４４ａ～１４４ｅが設けられている。また、各々の半硬質磁性体には、個別にコイルが設けられており、各半硬質磁性体を独立的に飽和領域で駆動することができる。従って、これらのコイルに供給する電流をオン／オフ制御することによって、所望の半硬質磁性体のみを動作させ、段階的に電磁石で発生する磁界を安定に設定することができる。

【０１２５】次に、本発明に係わる光可変減衰器の第７の原理について説明する。ウェッジ状複屈折結晶を利用した光可変減衰器では、図３０の従来の光可変減衰器で説明したように、僅かな偏光依存性損失（ＰＤＬ）が発生する。本発明に係わる光可変減衰器は、この偏光依存性損失をさらに低減する。

【０１２６】図２６は、本発明に係わる光可変減衰器の第７の原理を説明するための構成例である。（Ａ）は、上面図、（Ｂ）は、側面図である。図２７は、本発明に係わる光可変減衰器の第７の原理を説明するためのバイアス磁界の方向パターンを示す図である。（Ａ）は、バイアス磁界を屈折平面に垂直に印加する場合、（Ｂ）は、バイアス磁界を屈折平面と平行に印加する場合である。

【０１２７】図２６に示す光可変減衰器は、図３０に示す光可変減衰器と比べて、ファラデー素子１５０の磁区を単一にするためのバイアス磁界１５４が示されている。このバイアス磁界１５４は、光ビームに対して垂直にファラデー素子１５０に印加される。バイアス磁界１５４を発生するための磁石１５２は、図２６の（Ｂ）のみに示されており、（Ａ）では省略されている。また、実際には、ファラデー回転を発生させるため、光ビームと平行な磁界もファラデー素子１５０に印加される。しかし、これらの図では、説明を簡単にするため、光ビームと平行な磁界の図示は省略されている。その他の構成は、図３０に示す光可変減衰器と同じであり、同じ機能を有するエレメントには同じ参照番号を付している。

【０１２８】図２６の光可変減衰器では、光ビームは複屈折結晶８ａにおいて複屈折され、屈折角度の異なる常光及び異常光の成分を有する光ビームに変換される。常光及び異常光は、ファラデー素子１５０においてバイアス磁界１５４を供給される。このバイアス磁界１５４は、常光１５６及び異常光１５８で構成される平面（屈折平面と称する）に対して垂直に印加されている。この様子は、図２７の（Ａ）にも示されている。従って、常光１５６及び異常光１５８共に、同じ大きさのバイアス磁界１５４が印加される。

【０１２９】これに対して、図２７の（Ｂ）に示すように、バイアス磁界は、屈折平面に対して平行に印加することもできる。ただし、バイアス磁界は、光ビームに対して実質的に垂直に印加される。この場合、常光１５６及び異常光１５８は異なる屈折角を有しているため、各光に印加されるバイアス磁界は、僅かに異なる。この磁界の大きさの差によって、偏光依存性損失が発生すると考えられる。

【０１３０】従って、図２６や図２７（Ａ）に示すように、バイアス磁界を屈折平面に実質的に垂直に印加することによって、偏光依存性損失を低減することができる。この明細書において上述した本発明に係わる光可変減衰器では、２種類の磁気回路を利用して減衰量の制御が行なわれるため、光可変減衰器の外部に磁気回路の磁場が漏洩する恐れがある。特に、永久磁石の磁場は強く、外部への影響が大きい。この影響を軽減させるために、永久磁石にも電磁石と同様にヨークを設けたり、筐体を磁気シールドする方法が有効である。

【０１３１】以上、本発明の実施例により説明したが、本発明はこれらの実施例に限定されるものではなく、本発明の範囲内で改良及び変形が可能であることは言うまでもない。

【０１３２】

【発明の効果】上述したように、本発明によれば以下に示す効果を有する。請求項１乃至３のうちいずれか１項記載の光可変減衰器においては、前記検光子の偏光方向

は、前記磁気光学結晶における偏光方向の回転が無い場合の前記光ビームの偏光方向と実質的に直交状態に設定されている。

【０１３３】この場合、ファラデー回転角が大きいと、波長の変化に対するファラデー回転角の変化量も大きい。しかし、ファラデー回転角の変化に対する減衰量の変化量は小さいので、波長の変化に対する減衰量の変化量を低減できる。また、ファラデー回転角が小さいと、波長の変化に対するファラデー回転角の変化量も小さい。従って、この場合、ファラデー回転角の変化に対する対する減衰量の変化量が大きいが、波長の変化に対する減衰量の変化量を低減できる。

【０１３４】従って、本光可変減衰器では、減衰量の波長依存性を低減できる。また、同様に同様に減衰量の温度依存性も低減できる。請求項４乃至６のうちいずれか１項記載の光可変減衰器においては、永久磁石で発生された磁界或いはその一部が、磁気光学結晶に光ビームと平行に常に印加されている。従って、本光可変減衰器では、故障等で、磁気回路へ印加する電流が流れなくなっても、光ビームを透過することができる。その結果、伝送装置の動作に与える影響を低減できる。さらに、波長・温度依存性を低減することもできる。

【０１３５】特に、請求項５記載の光可変減衰器では、より簡易な構成で、上述の効果を得ることができる。請求項７乃至１０のうちいずれか１項記載の光可変減衰器においては、磁気光学結晶（ファラデー素子）は、ヨークのギャップ中に隙間なく挿入できる。従って、ヨークで発生した磁界は、外部に洩れることなく効率良く磁気光学結晶に供給でき、その結果、磁気光学結晶に強い磁場を均一に印加することができる。よって、磁気光学結晶とヨークとの間に隙間がある構成に比べて、磁気回路に供給する電流を低減でき、磁気回路の駆動電力を低減できる。

【０１３６】特に、請求項８記載の光可変減衰器では、コイルが磁気光学結晶の近傍に設けられていることによって、ヨーク中の磁気抵抗の影響が低減され、効率よくヨークで発生した磁界を磁気光学結晶に供給することができる。従って、電磁石の駆動電力をより低減できる。さらに、ヨークのループ側の高さを低くできるので、光可変減衰器の高さも低くでき、その結果、実装の容易性が向上する。

【０１３７】また、請求項９又は１０記載の光可変減衰器では、ヨークのギャップの間隔を例えば、２００μｍ程度まで狭くすることができる。従って、ヨークで発生した磁界を効率よくファラデー素子に印加でき、駆動電力を一層低減することができる。

【０１３８】請求項１１又は１２記載の光増幅装置、及び請求項１３記載の光可変減衰器においては、検光子の偏光方向、光信号の偏光方向、及び磁気光学結晶を調節することによって、減衰量の波長依存性を任意に設定できる。従って、利得等化用の光フィルタを使用しないで、光増幅器の利得の波長依存性を低減することができる。また、本光可変減衰器では、減衰量が大きいほど波長依存性が大きくできる。従って、光励起パワーの上限値が小さい場合の光増幅器の利得の波長依存性を良好にキャンセルできる。よって、光ファイバ増幅器の励起光のパワーを小さく設定することができ、光ファイバ増幅器の小型化、低消費電力化が可能になる。

【０１３９】請求項１４乃至１６のうちいずれか１項記載の光可変減衰器においては、出力側受光器でモニタした光可変減衰器の出力パワーパワーが所定の値になるように制御されたり、入力側受光器でモニタした光ビームのパワーと出力側受光器でモニタした光可変減衰器の出力パワーとの比が所定の値になるように制御される。従って、光可変減衰器の減衰量の温度特性、経時劣化、偏波ロス変動等の補正が可能になる。

【０１４０】請求項１７記載の光可変減衰器においては、磁気回路をリング状ヨークで構成すると、光ビームの上側と下側にそれぞれリング状ヨークの半径に相当するスペースを確保するだけでよい。従って、光可変減衰器の高さを低くすることができる。

【０１４１】請求項１８又は１９記載の光可変減衰器においては、磁気回路の磁界を効率的に磁気光学結晶に印加できる。従って、磁気回路は、外部に磁場を漏洩することを防ぐことができ、他の磁石への影響も低減できる。請求項２０記載の光可変減衰器においては、ヨークは少なくとも一部に半硬質磁性体を含む。従って、パルス電流の印加でヨークが磁化され、電流の供給を停止してもその磁化は保持される。よって、光可変減衰器の消費電力を低減できる。

【０１４２】請求項２１記載の光可変減衰器においては、磁化の異なる複数の半硬質磁性体を制御することによって、電磁石で発生する磁界を安定に段階的に設定することができる。請求項２２記載の光可変減衰器においては、磁気光学結晶の磁区を単一化するためのバイアス磁界を屈折平面に実質的に垂直に印加される。それにより偏光依存性損失を低減することができる。

【図面の簡単な説明】

【図１】本発明に係わる光可変減衰器の構成例。

【図２】偏光子（Ｐ）、ファラデー素子（ＦＲ）、検光子（Ａ）の配置例。（Ａ）は、０度配置と称し、偏光子の偏光方向と検光子の偏光方向が平行である場合、（Ｂ）は、４５度配置と称し、偏光子の偏光方向と検光子の偏光方向との角度差が４５度の場合、（Ｃ）は、９０度配置と称し、偏光子の偏光方向と検光子の偏光方向が直交している場合。

【図３】０度配置の場合のファラデー回転角に対する減衰量の計算結果。

【図４】４５度配置の場合のファラデー回転角に対する減衰量の計算結果。

【図５】９０度配置の場合のファラデー回転角に対する減衰量の計算結果。

【図６】ファラデー回転角と波長或いは温度の変化に対するファラデー回転角の変化量との模式的な関係図。

【図７】偏光子と検光子の偏光方向の角度差が０度の場合の、波長に対する減衰特性。（Ａ）は、波長に対する任意の減衰量の変化、（Ｂ）は、波長に対する任意の減衰量の偏差。

【図８】偏光子と検光子の偏光方向の角度差が４５度の場合の、波長に対する減衰特性。（Ａ）は、波長に対する任意の減衰量の変化、（Ｂ）は、波長に対する任意の減衰量の偏差。

【図９】偏光子と検光子の偏光方向の角度差が７０度の場合の、波長に対する減衰特性。（Ａ）は、波長に対する任意の減衰量の変化、（Ｂ）は、波長に対する任意の減衰量の偏差。

【図１０】偏光子と検光子の偏光方向の角度差が８０度の場合の、波長に対する減衰特性。（Ａ）は、波長に対する任意の減衰量の変化、（Ｂ）は、波長に対する任意の減衰量の偏差。

【図１１】偏光子と検光子の偏光方向の角度差が９０度の場合の、波長に対する減衰特性。（Ａ）は、波長に対する任意の減衰量の変化、（Ｂ）は、波長に対する任意の減衰量の偏差。

【図１２】本発明に係わる光可変減衰器の他の構成例。

【図１３】本発明に係わる光可変減衰器の第２の原理を説明するための図。

【図１４】図１３に示す光可変減衰器の変更例。

【図１５】図１４に示す光可変減衰器の変更例。

【図１６】本発明に係わる光可変減衰器の磁気回路の構成例。

【図１７】図１６に示した光可変減衰器の磁気回路の変更例。（Ａ）は、上から見た断面図、（Ｂ）は、横から見た断面図。

【図１８】本発明の光可変減衰器のその他の構成例。

【図１９】典型的なＥＤＦＡの増幅特性。

【図２０】光可変減衰器が組み込まれた光伝送装置の構成例。

【図２１】光ファイバ増幅器の波長依存性をキャンセルするために調整された光可変減衰器の減衰特性。

【図２２】本発明に係わる光可変減衰器の第５の原理を説明するための構成例。

【図２３】図２２に示す光可変減衰器の変更例。

【図２４】本発明に係わる光可変減衰器の第６の原理を説明するための構成例。（Ａ）は、外観図、（Ｂ）は、上面図、（Ｃ）は、正面図。

【図２５】本発明に係わる光可変減衰器に使用する電磁石の構成を示す図。

【図２６】本発明に係わる光可変減衰器の第７の原理を説明するための構成例。（Ａ）は、上面図、（Ｂ）は、側面図。

【図２７】本発明に係わる光可変減衰器の第７の原理を説明するためのバイアス磁界の方向パターンを示す図。

【図２８】典型的な波長多重通信方式のシステム構成図。

【図２９】従来の光可変減衰器の第１の構成例。

【図３０】従来の光可変減衰器の第２の構成例。

【図３１】磁界Ｈとファラデー回転角との関係。

【符号の説明】

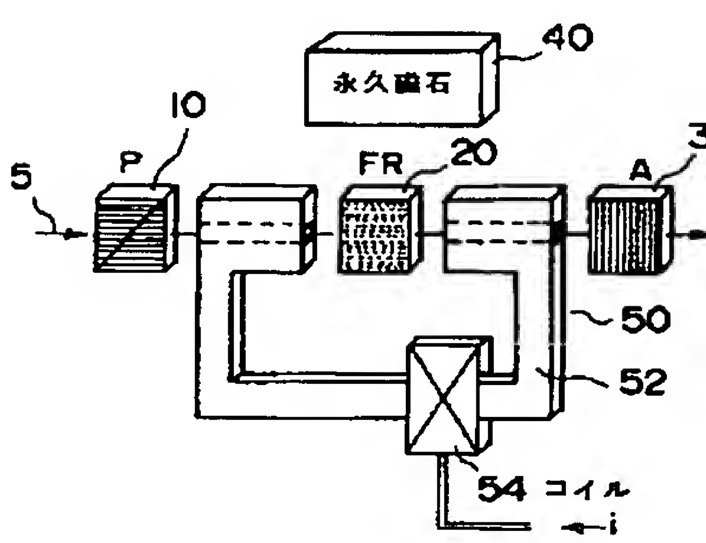
１　磁気光学結晶（ファラデー素子）
２　偏光子
３　永久磁石
４　電磁石
５　光ビーム
６ａ、６ｂ　光ファイバ
７ａ、７ｂ　レンズ
８ａ、８ｂ　複屈折結晶
９　ファラデー回転子
１０　偏光子
２０、２２　磁気光学結晶（ファラデー素子）
３０　検光子
４０、４２　永久磁石
５０、５５、６０、８０　電磁石
５２、５７、６２、８２　ヨーク
５４、５９、６４、８４　コイル
６６　永久磁石
７０　永久磁石
８６－１、８６－２　コイル
１００、１００ａ、１００ｂ　光カプラ
１０２　レンズ
１０４　アパーチャ
１０６、１０６ａ、１０６ｂ　受光器
１０８、１０８ａ、１０８ｂ　増幅器
１１０　誤差検出回路
１１２　制御電圧発生回路
１１４　リニアライザ
１１６　位相補償回路
１１８　駆動回路
１２０　割算回路
１３０　ファラデー素子
１３２　電磁石
１３４　ヨーク
１３６　コイル
１３８　永久磁石
１４０　光ビーム
１４２　筐体
１５０　ファラデー素子
１５２　磁石
１５４　バイアス磁界
１５６　常光

33

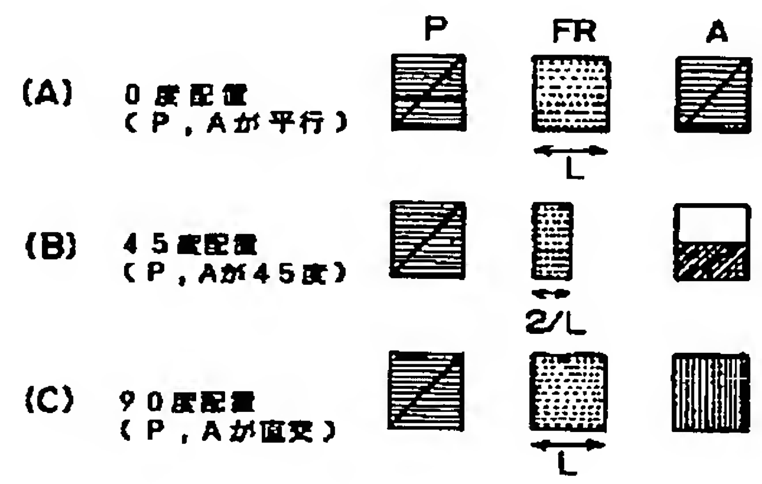
34

１５８ 異常光

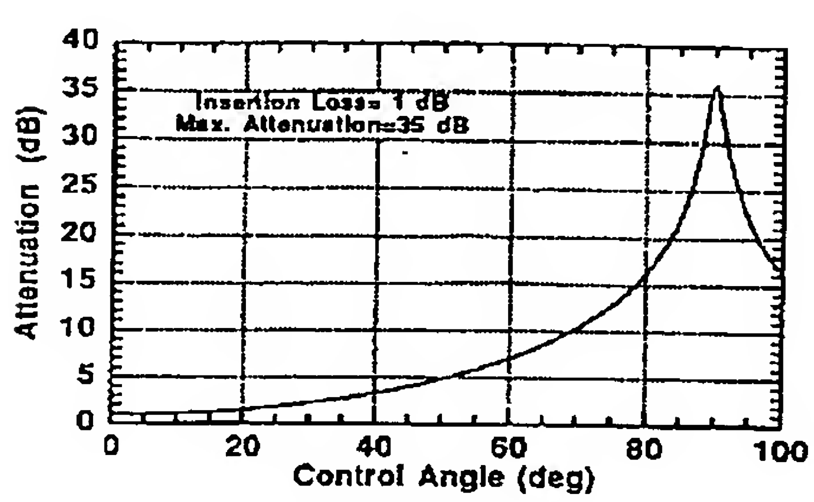
【図１】



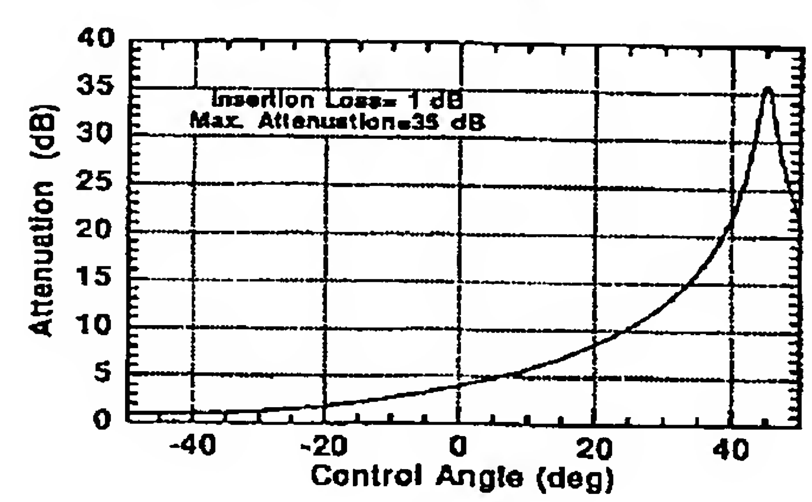
【図２】



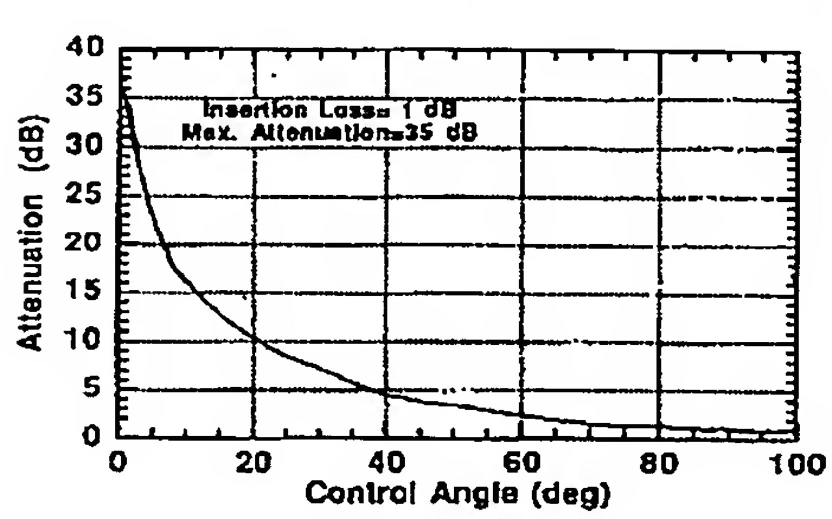
【図３】



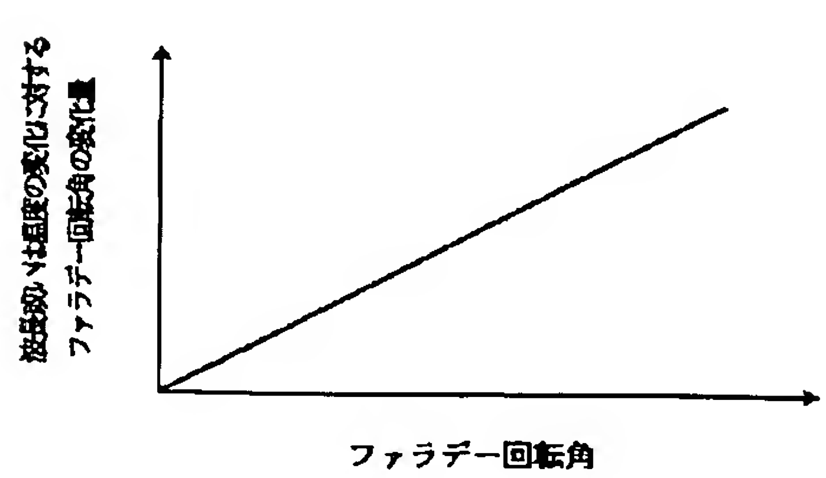
【図４】



【図５】

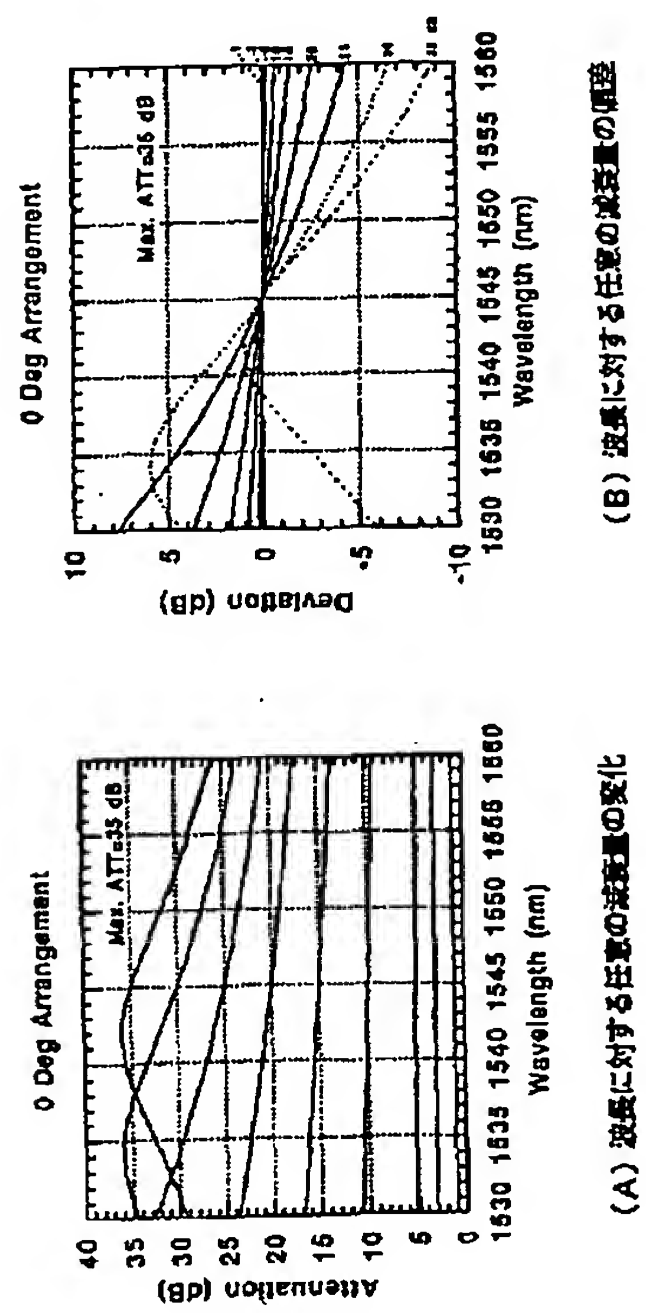


【図６】



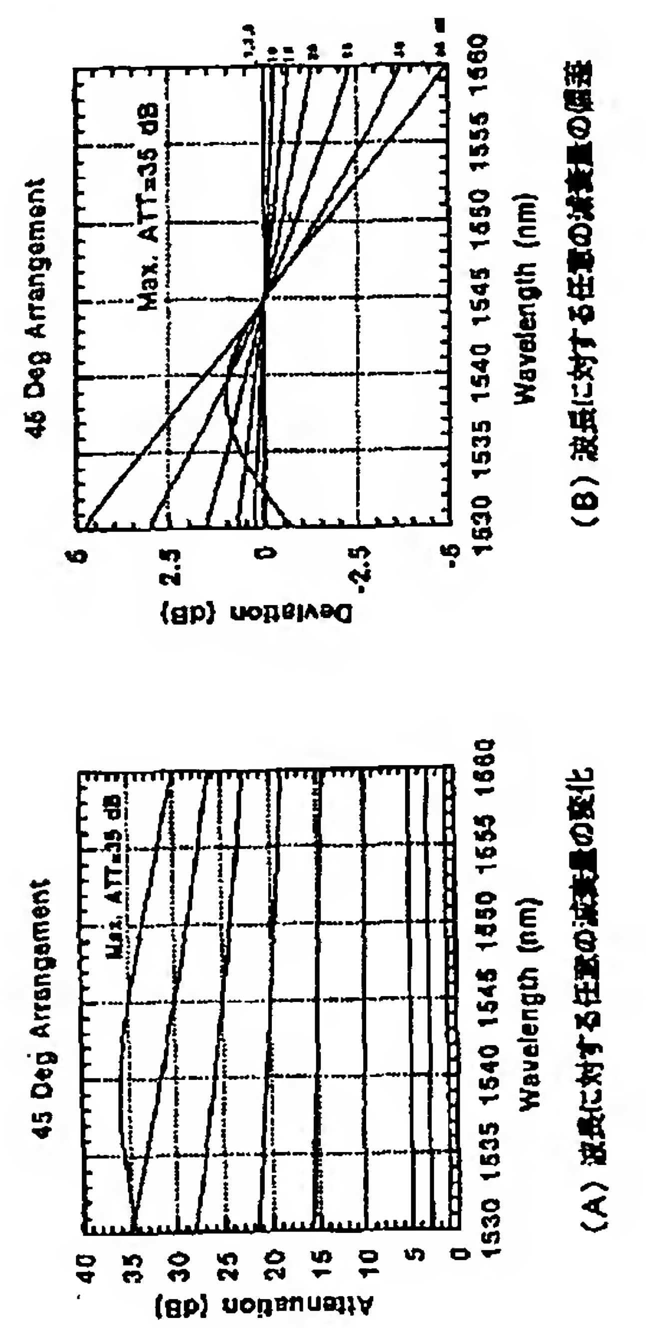
【図７】

偏光子と検光子の偏光方向の角度差が０度の場合の波長に対する減衰特性



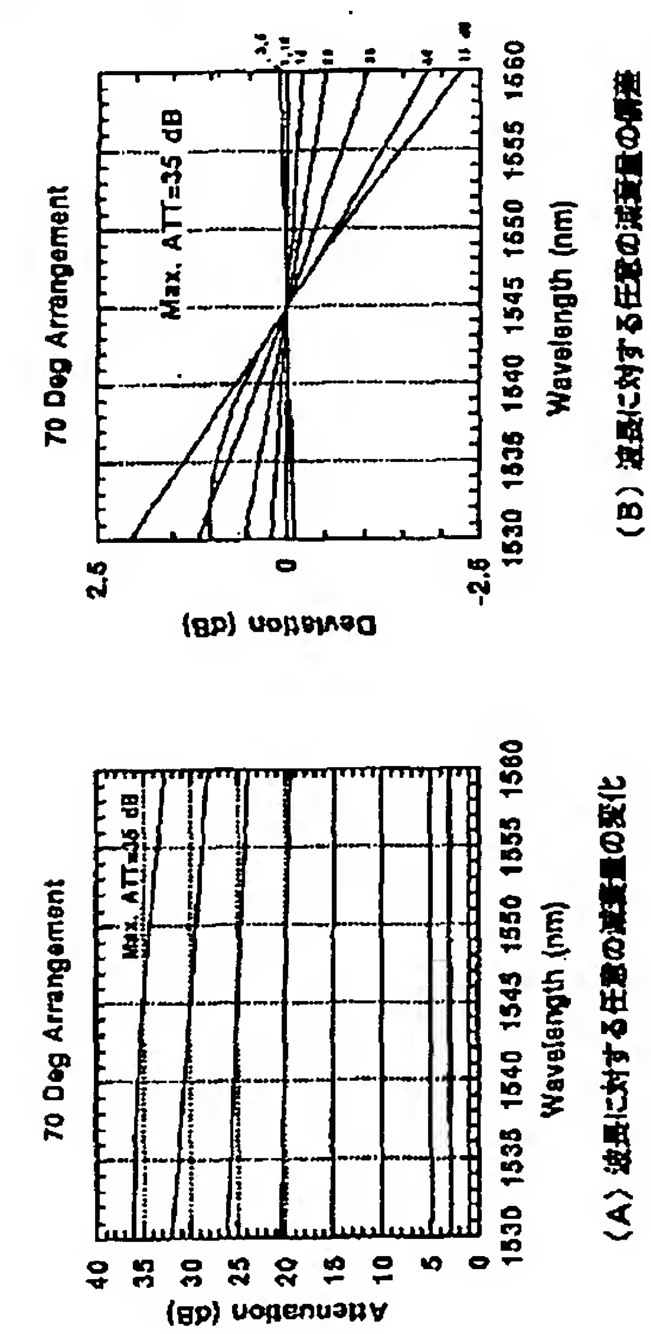
【図８】

偏光子と検光子の偏光方向の角度差が４５度の場合の波長に対する減衰特性



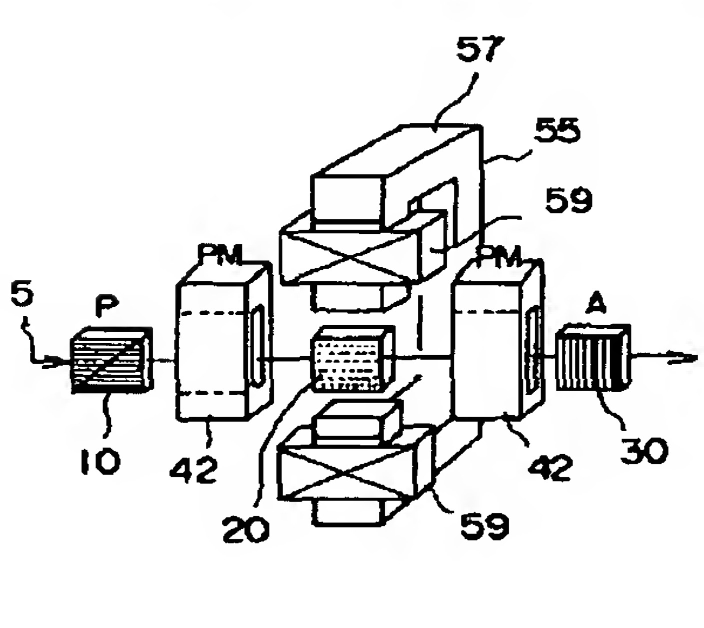
【図９】

偏光子と検光子の偏光方向の角度差が７０度　場合の波長に対する減衰特性



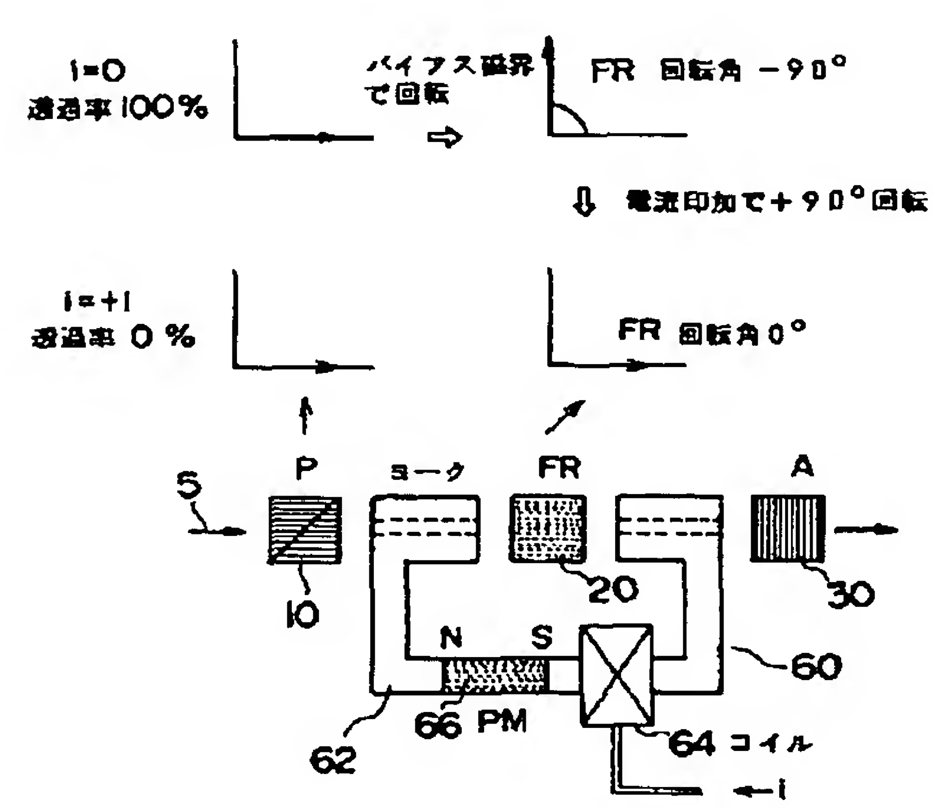
【図１２】

本発明に係わる光可変減衰器の他の構成例



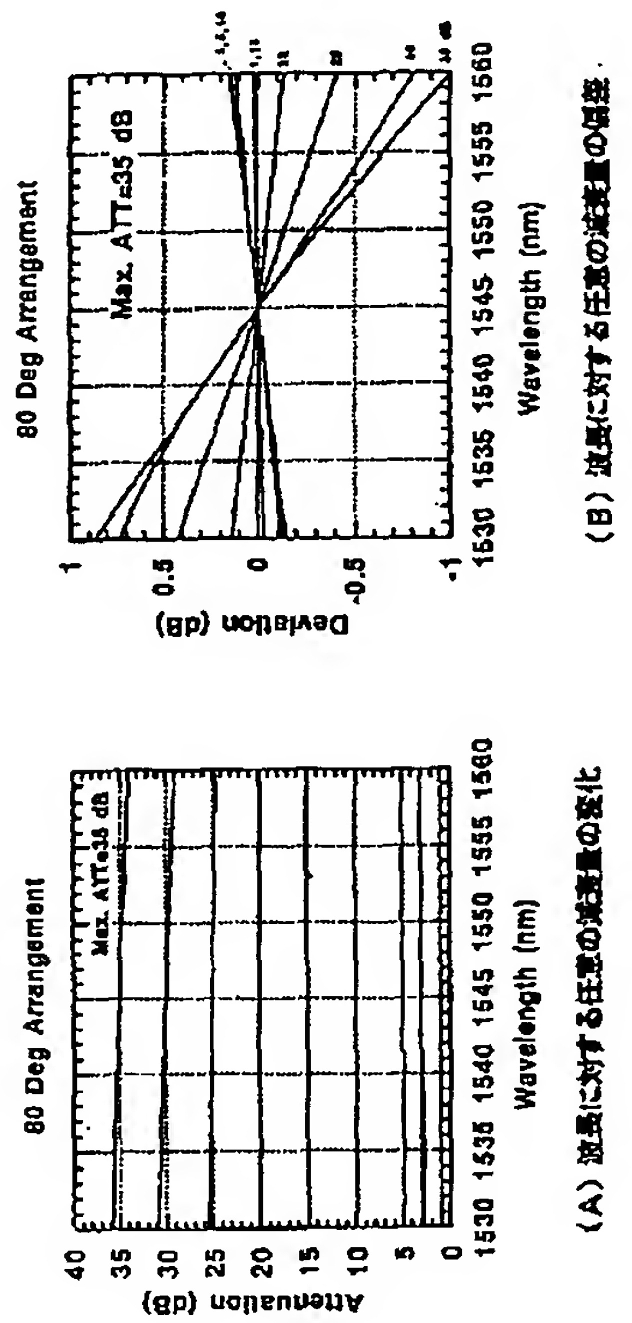
【図１３】

本発明に係わる光可変減衰器の第２の原理を説明するための図



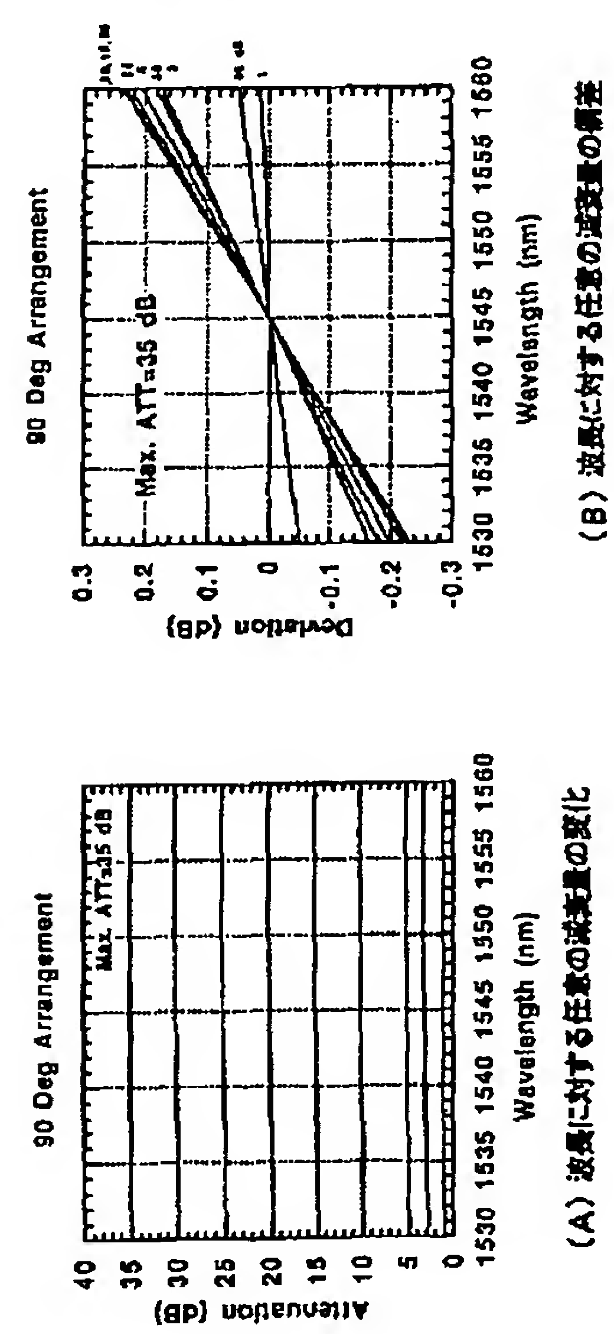
【図１０】

偏光子と検光子の偏光方向の角度差が８０度の場合の波長に対する減衰特性



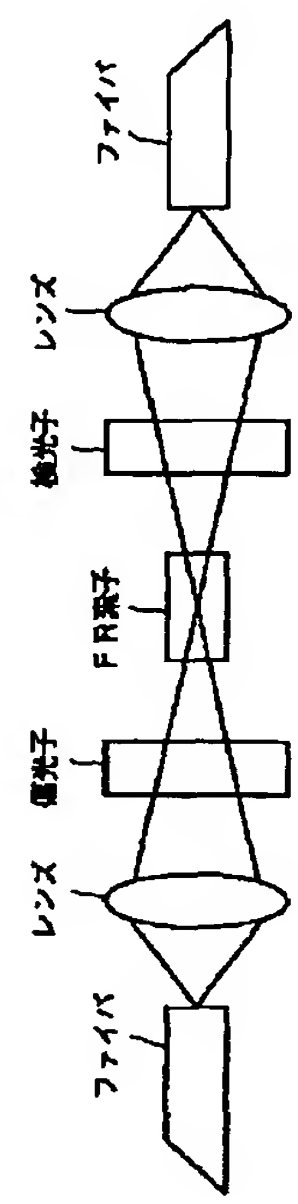
【図１１】

偏光子と検光子の偏光方向の角度差が９０度の場合の波長に対する減衰特性



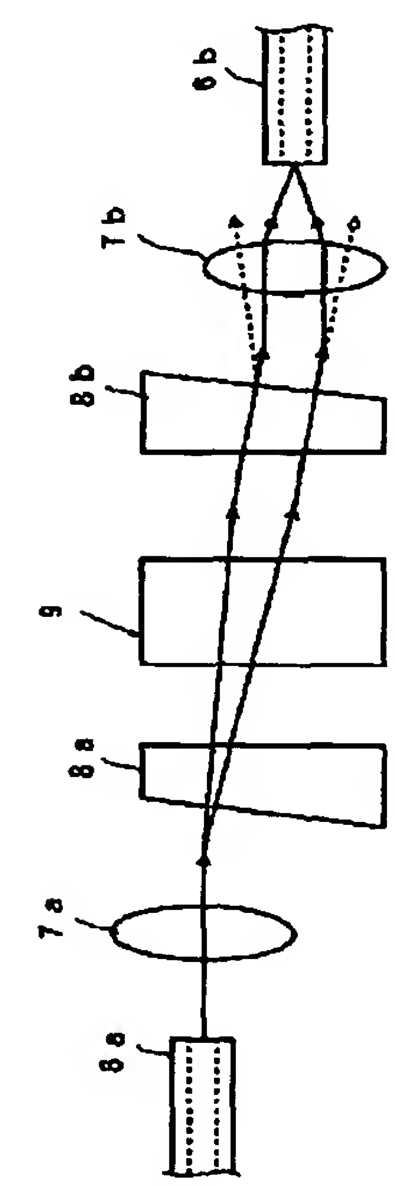
【図１８】

本発明の光可変減衰器のその他の構成例



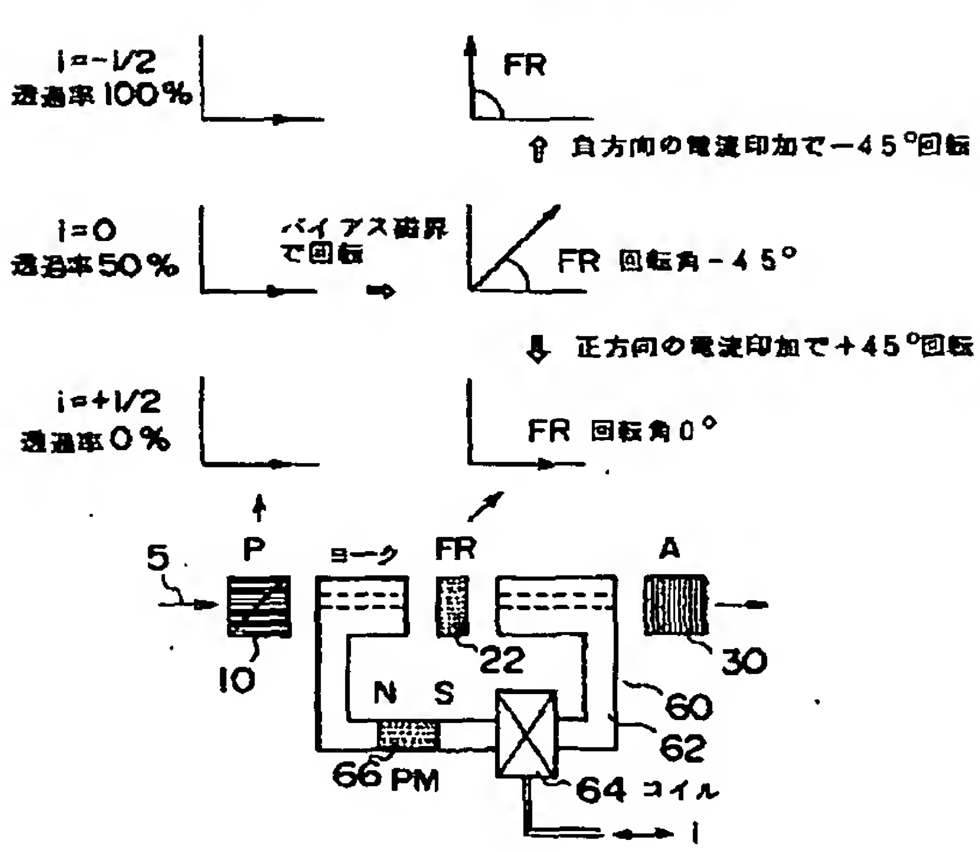
【図３０】

従来の光可変減衰器の第２の構成例



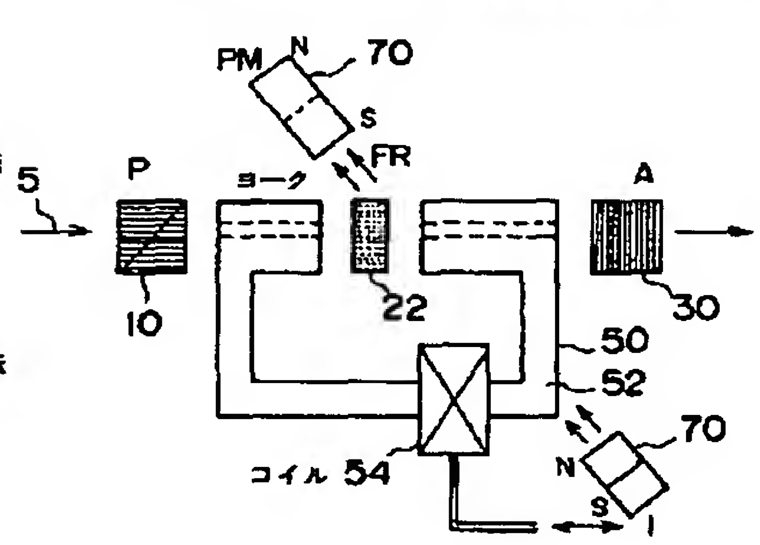
【図１４】

図１３に示す光可変減衰器の変更例



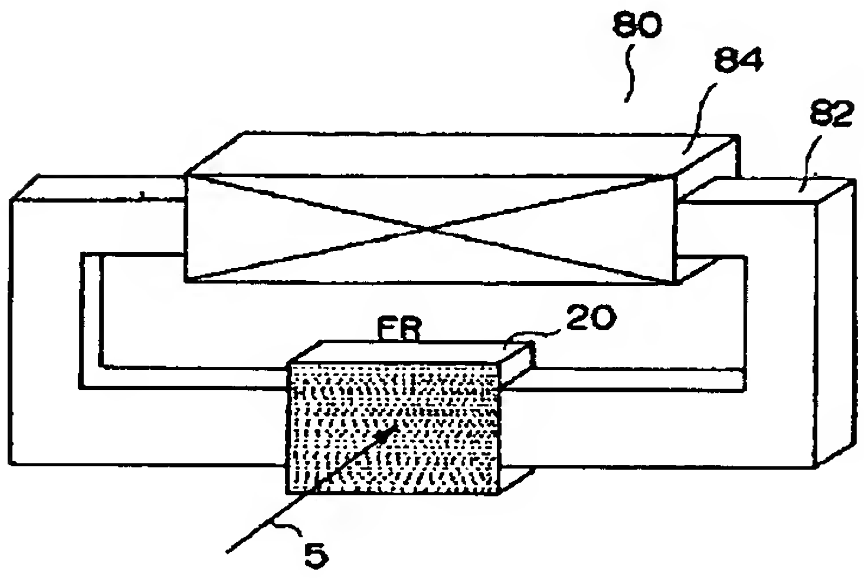
【図１５】

図１４に示す光可変減衰器の変更例



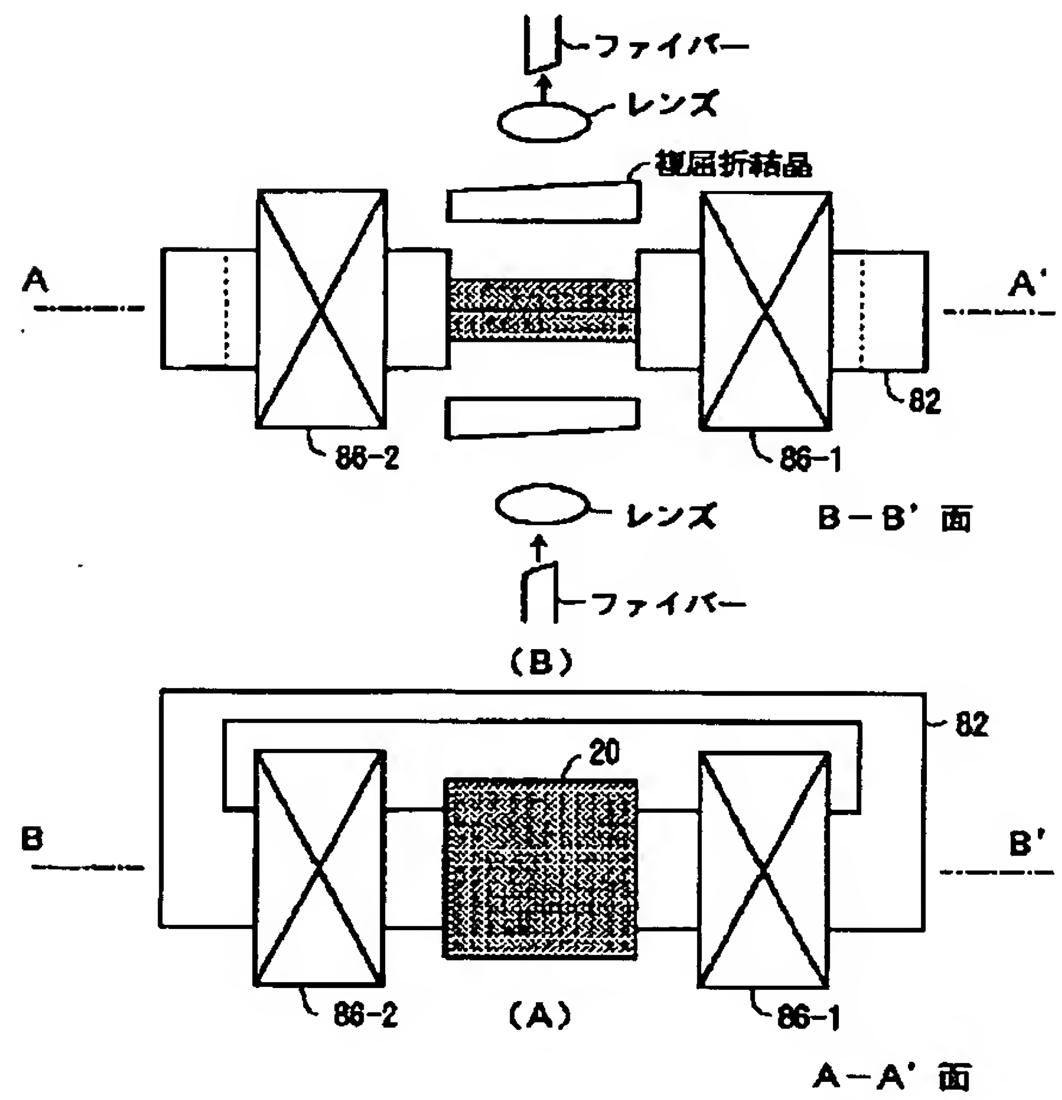
【図16】

本発明に係わる光可変減衰器の磁気回路の構成例



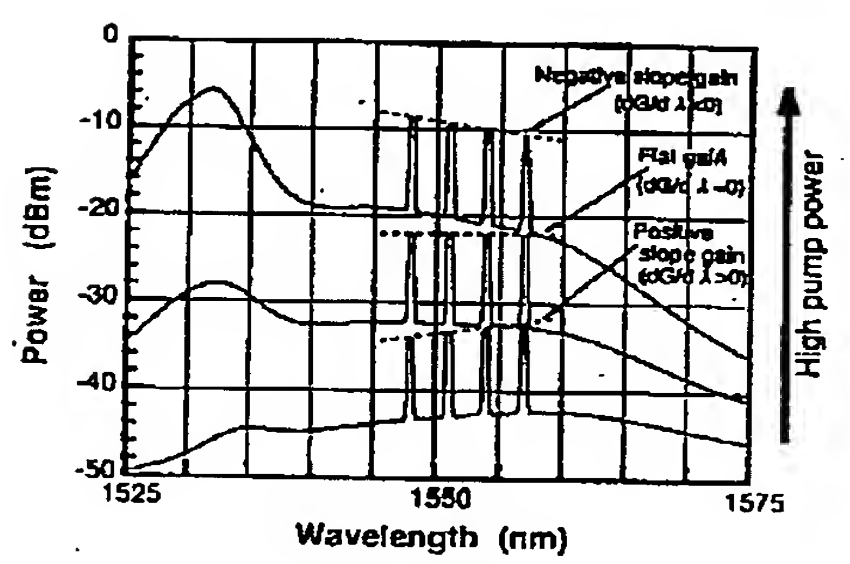
【図17】

図18に示した光可変減衰器の磁気回路の変更例
（A）は上から見た断面図、（B）は横から見た断面図



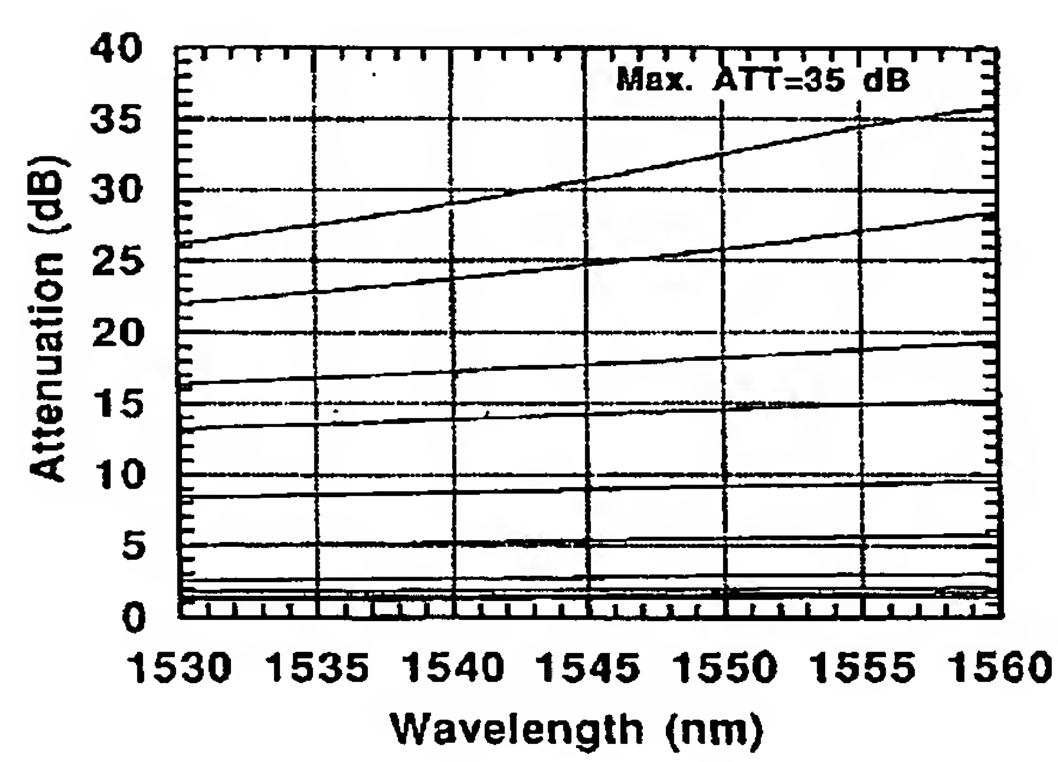
【図19】

典型的なＥＤＦＡの増幅特性



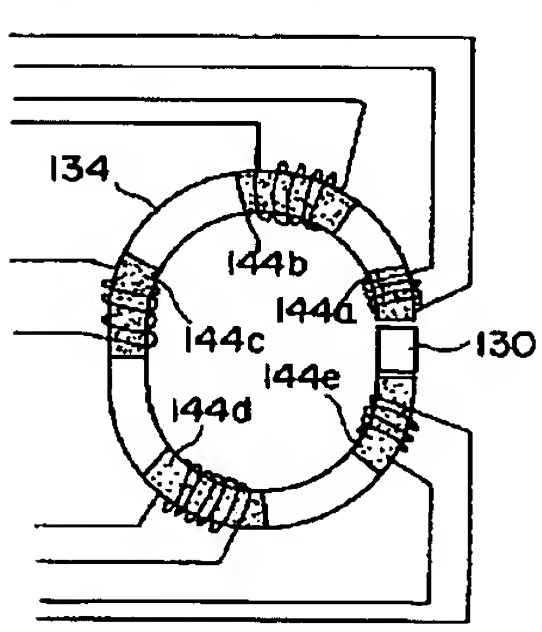
【図21】

光ファイバ増幅器の波長依存性をキャンセルするために
調整された光可変減衰器の減衰特性



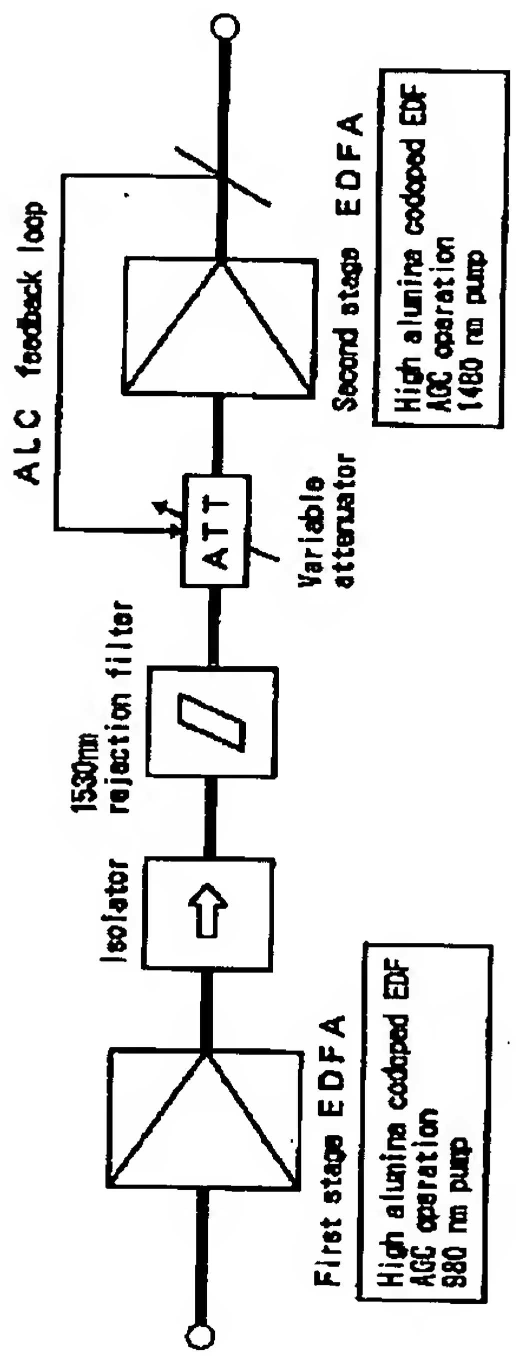
【図25】

本発明に係わる光可変減衰器に使用する
電磁石の構成を示す図



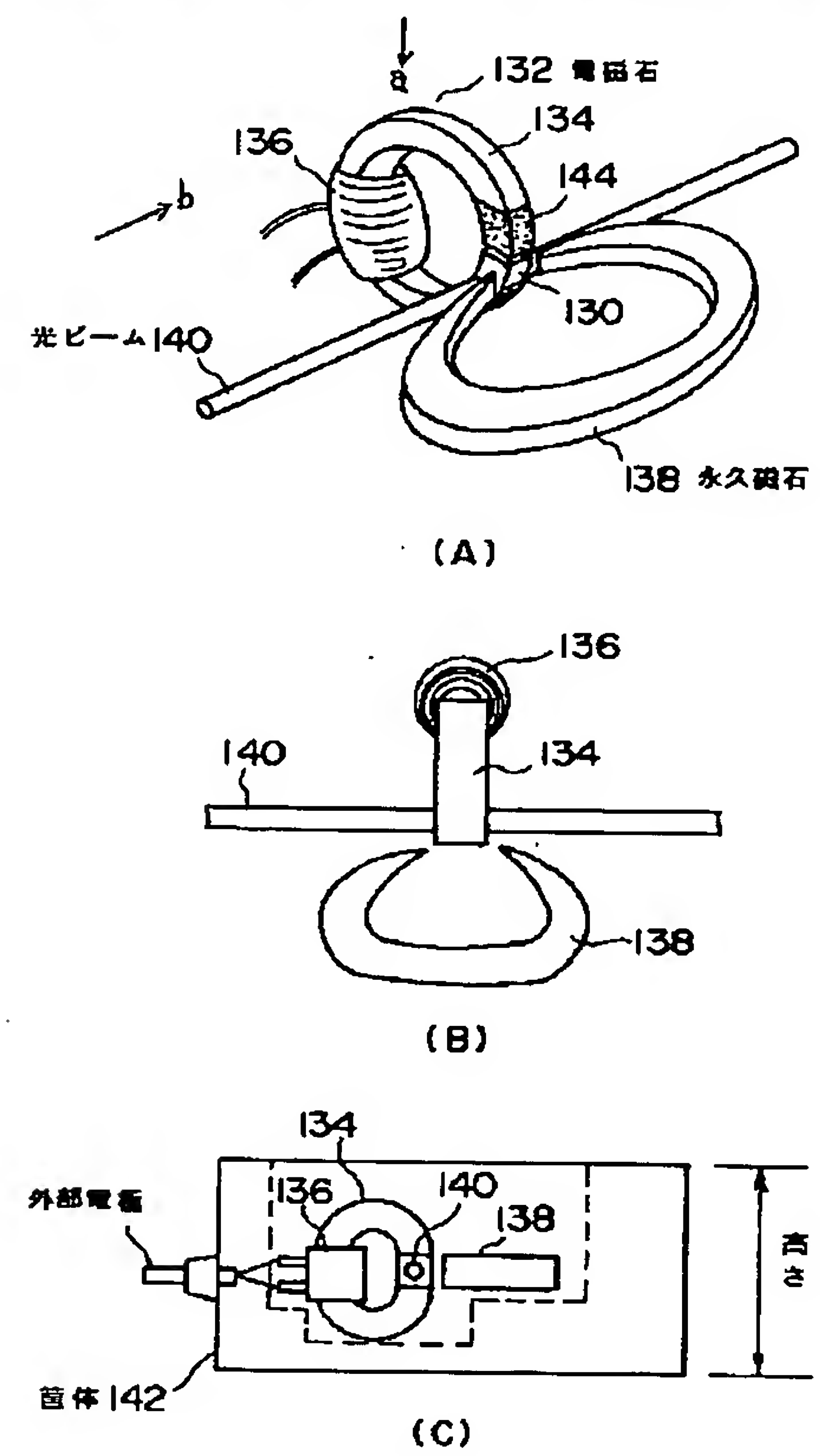
【図２０】

光可変減衰器が組み込まれた光伝送装置の構成例



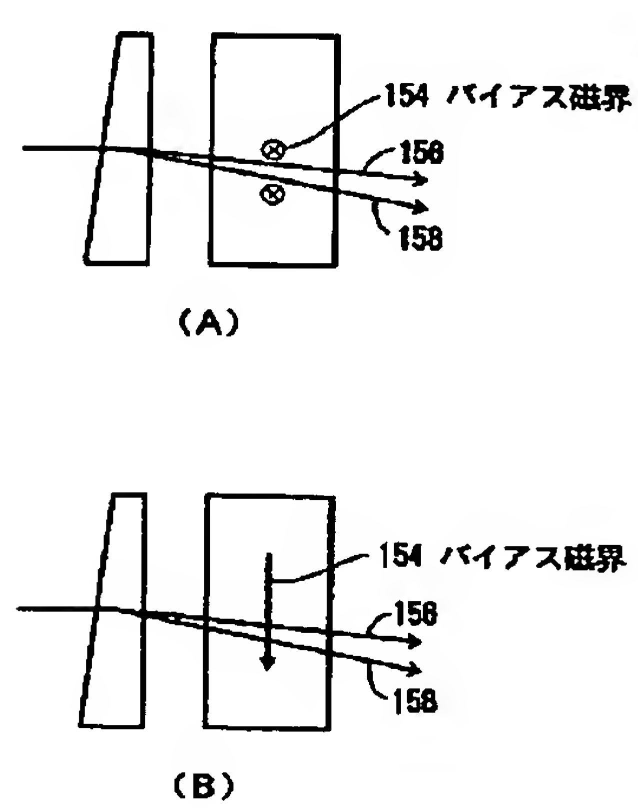
【図２４】

本発明に係わる光可変減衰器の第６の原理を説明するための構成例。(A)は外観図、(B)は、上面図、(C)は、正面図



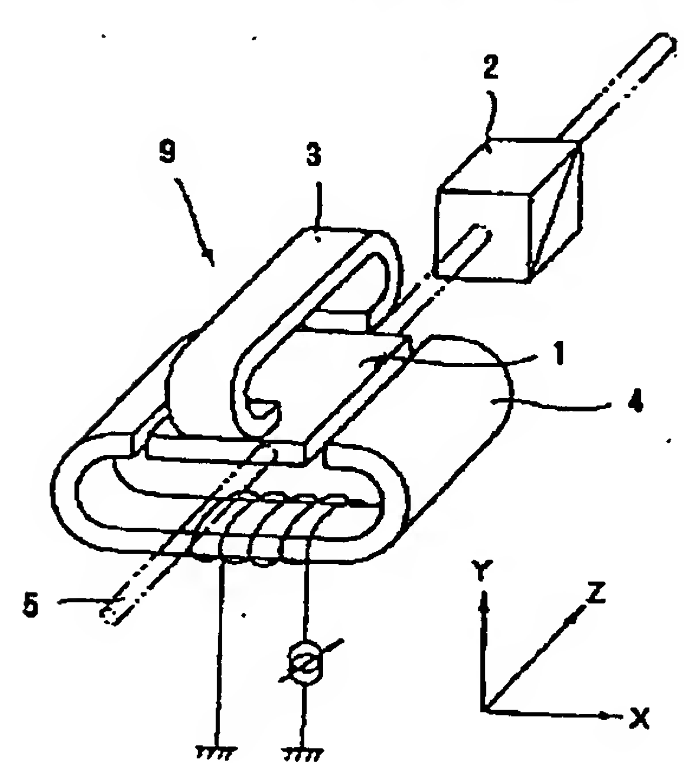
【図２７】

本発明に係わる光可変減衰器の第７の原理を説明するためのバイアス磁界の方向パターンを示す図



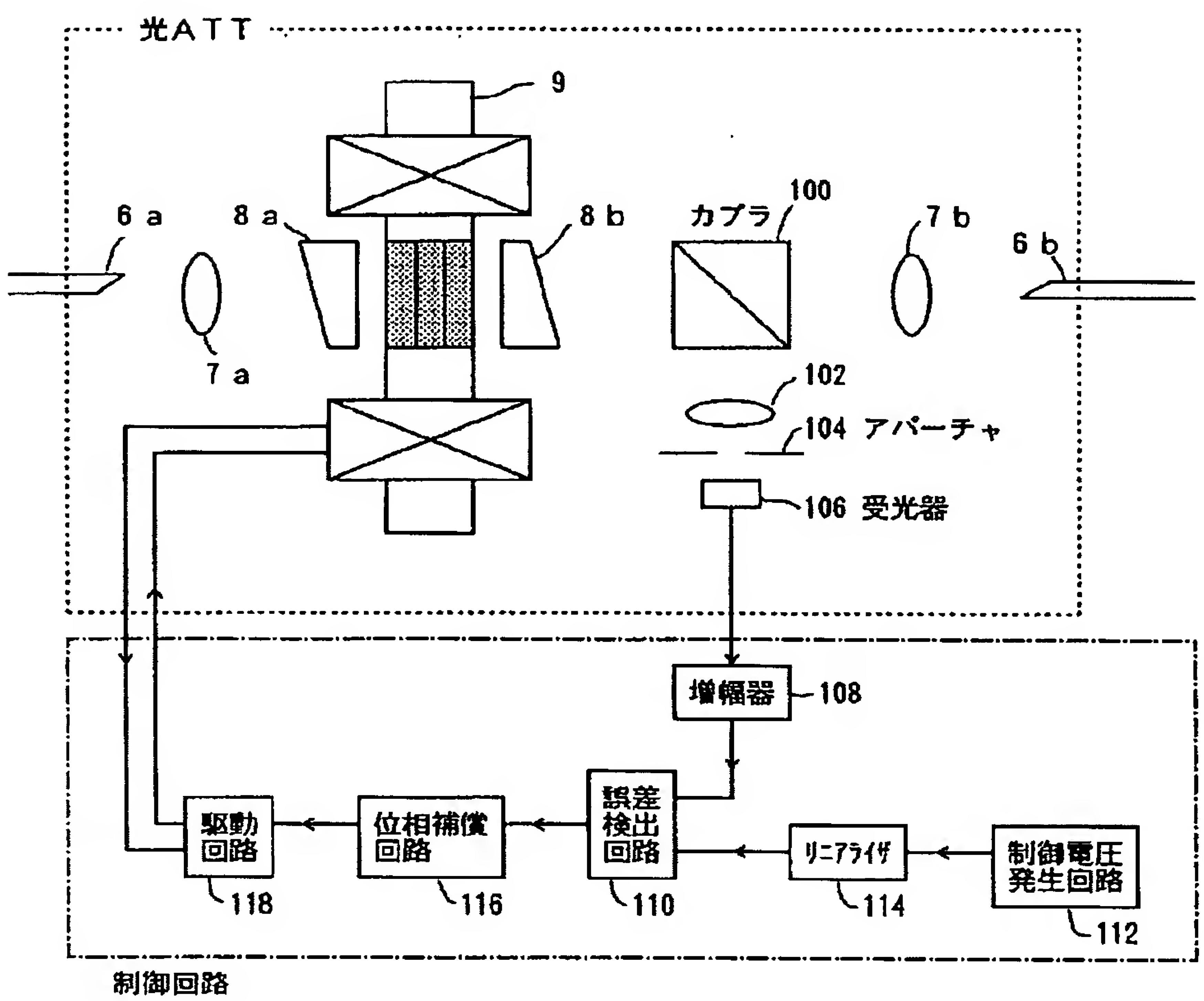
【図２９】

従来の光可変減衰器の第１の構成例



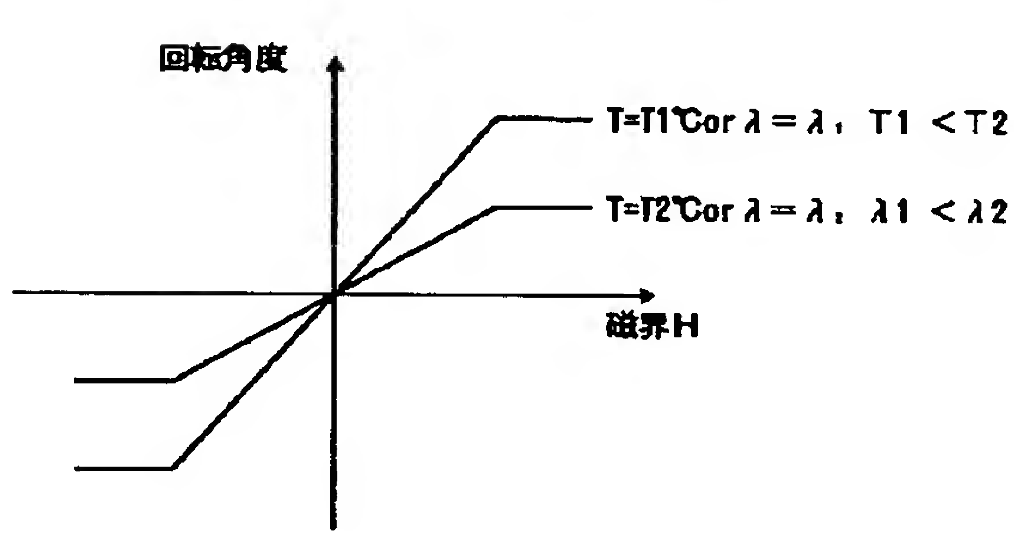
【図２２】

本発明に係わる光可変減衰器の第５の原理を説明するための構成例



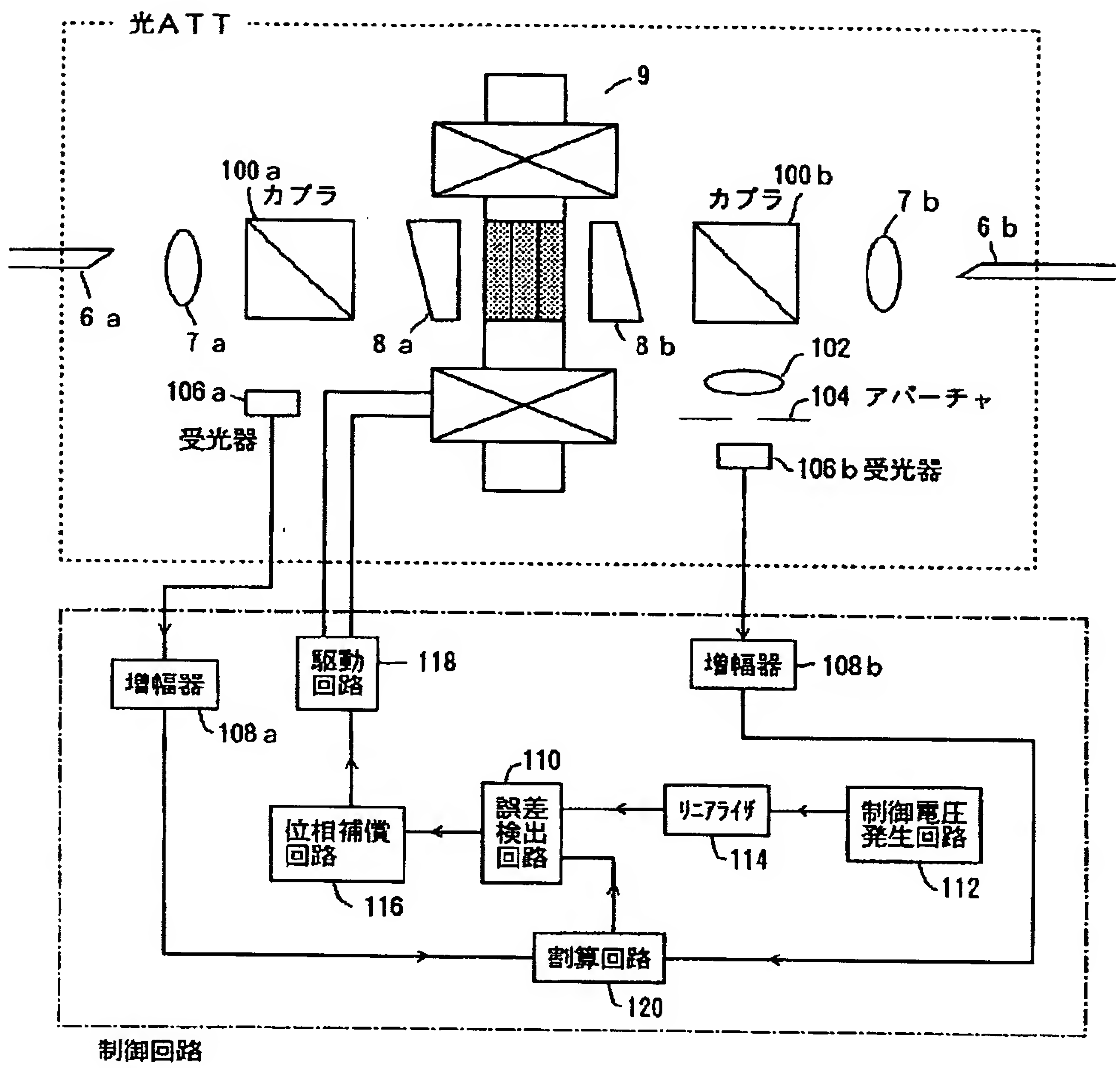
【図３１】

磁界Ｈとファラデー回転角との関係



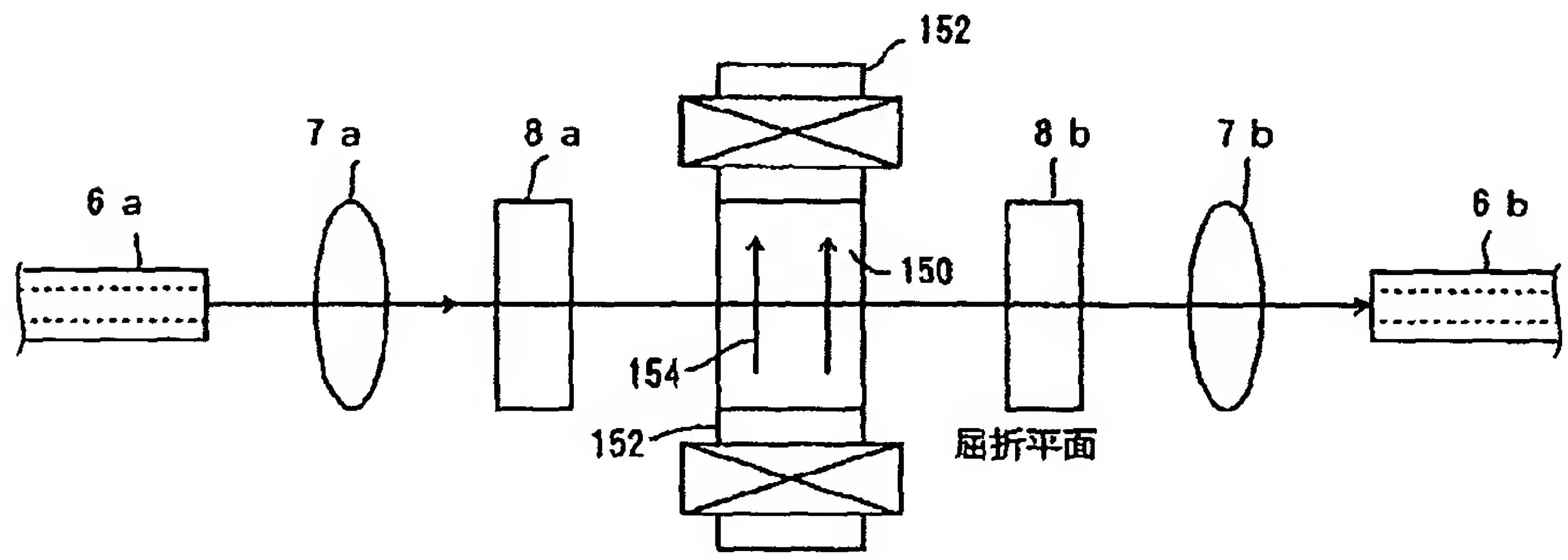
【図２３】

図２２に示す光可変減衰器の変更例

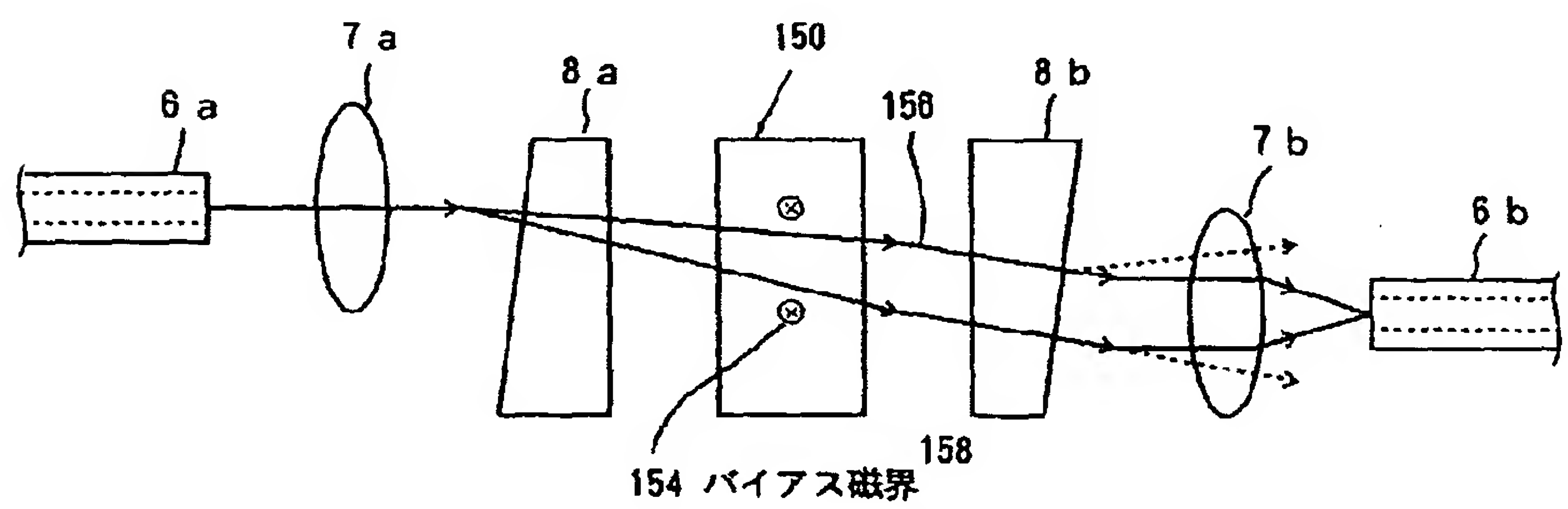


【図２６】

本発明に係わる光可変減衰器の第７の原理を説明するための構成例



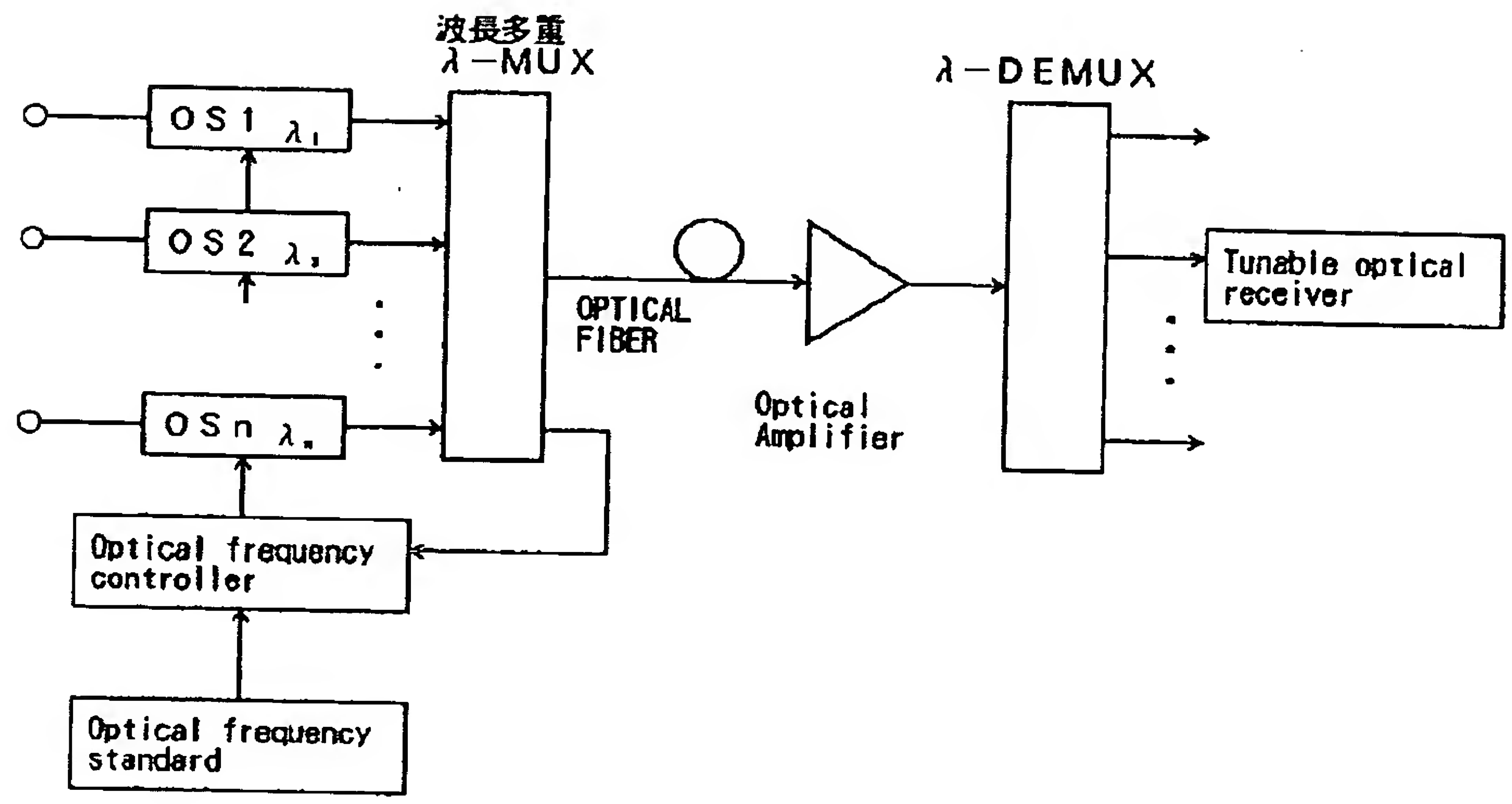
（A）上面図



（B）側面図

【図２８】

典型的な波長多重通信方式のシステム構成図



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